ASSOCIATION INTERNATIONALE DE GEODESIE

BUREAU GRAVIMETRIQUE INTERNATIONAL

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N° 71

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18, Avenue Edouard Belin
31055 TOULOUSE CEDEX
FRANCE

INFORMATIONS FOR CONTRIBUTORS

Contributors should follow as closely as possible the rules below :

Manuscripts should be typed (double-spaced) in Prestige-Elite characters (IBM-type), on one side of plain paper 21 cm x 29,7 cm, with a 2 cm margin on the left and right hand sides as well as on the bottom, and with a 3 cm margin at the top (as indicated by the frame drawn on this page).

Title of paper. Titles should be carefully worded to include only key words.

Abstract. The abstract of a paper should be informative rather than descriptive. It is not a table of contents. The abstract should be suitable for separate publication and should include all words useful for indexing. Its length should be limited to one typescript page.

Table of contents. Long papers may include a table of contents following the abstract.

Footnotes. Because footnotes are distracting, they should be avoided as much as possible.

Mathematics. For papers with complicated notation, a list of symbols and their definitions should be provided as an appendix. All characters that are available on standard typewriters should be typed in equations as well as test. Symbols that must be handwritten should be identified by notes in the margin. Ample space (1.9 cm above and below) should be allowed around equations so that type can be marked for the printer. Where an accent or underscore has been used to designate a special type face (e.g., boldface for vectors, script for transforms, sans serif for tensors), the type should be specified by a note in a margin. Bars cannot be set over superscripts or extended over more than one character. Therefore angle brackets are preferable to accents over characters. Care should be taken to distinguish between the letter 0 and zero, the letter l and the number one, kappa and k, mu and the letter u, nu and v, eta and n, also subscripts and superscripts should be clearly noted and easily distinguished. Unusual symbols should be avoided.

Acknowledgements. Only significant contributions by professional colleagues, financial support, or institutional sponsorship should be included in acknowledgements.

References. A complete and accurate list of references is of major importance in review papers. All listed references should be cited in text. A complete reference to a periodical gives author (s), title of article, name of journal, volume number, initial and final page numbers (or statement "in press"), and year published. A reference to an article in a book, pages cited, publisher's location, and year published. When a paper presented at a meeting is referenced, the location, dates, and sponsor of the meeting should be given. References to foreign works should indicate whether the original or a translation is cited. Unpublished communications can be referred to in text but should not be listed. Page numbers should be included in reference citations following direct quotations in text. If the same information has been published in more than one place, give the most accessible reference ; e.g. a textbook is preferable to a journal, a journal is preferable to a technical report.

Tables. Tables are numbered serially with Arabic numerals, in the order of their citation in text. Each table should have a title, and each column, including the first, should have a heading. Column headings should be arranged to that their relation to the data is clear.

Footnotes for the tables should appear below the final double rule and should be indicated by a, b, c, etc. Each table should be arranged to that their relation to the data is clear.

Illustrations. Original drawings of sharply focused glossy prints should be supplied, with two clear Xerox copies of each for the reviewers. Maximum size for figure copy is (25.4 x 40.6 cm). After reduction to printed page size, the smallest lettering or symbol on a figure should not be less than 0.1 cm high ; the largest should not exceed 0.3 cm. All figures should be cited in text and numbered in the order of citation. Figure legends should be submitted together on one or more sheets, not separately with the figures.

Mailing. Typescripts should be packaged in stout padded or stiff containers ; figure copy should be protected with stiff cardboard.

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BUREAU GRAVIMETRIQUE INTERNATIONAL

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Bulletin d'Information n° 71

PART I

INTERNAL MATTERS

GENERAL INFORMATIONS

1. HOW TO OBTAIN THE BULLETIN

The Bulletin d'Information of the Bureau Gravimétrique International is issued twice a year, generally at the end of June and end of December.

The Bulletin contains general informations on the community, on the Bureau itself. It informs about the data available, about new data sets...

It also contains contributing papers in the field of gravimetry, which are of technical character. More scientifically oriented contributions should better be submitted to appropriate existing journals.

Communications presented at general meeting, workshops, symposia, dealing with gravimetry (e.g. IGC, S.S.G.'s,...) are published in the Bulletin when appropriate - at least by abstract.

Once every four years, a special issue contains the National Reports as presented at the International Gravity Commission meeting. Other special issues may also appear (once every two years) which contain the full catalogue of the holdings.

About three hundred individuals and institutions presently receive the Bulletin.

You may :

- either request a given bulletin, by its number (71 have been issued as December 31,1992, but numbers 2,16, 18,19 are out of print).

- or subscribe for regularly receiving the two bulletins per year plus the special issues.

Requests should be sent to:

Mrs. Nicole LESTIEU
CNES/BGI
18, Avenue Edouard Belin
31055 TOULOUSE CEDEX - FRANCE

Bulletins are sent on an exchange basis (free of charge) to individuals, institutions which currently provide informations, data to the Bureau. For other cases, the price of each issue is 70 FF.

2. HOW TO REQUEST DATA

2.1. Stations descriptions Diagrams for Reference, Base Stations (including IGSN 71's)

Request them by number, area, country, city name or any combination of these.

When we have no diagram for a given request, but have the knowledge that it exists in another center, we shall in most cases forward the request to this center or/and tell the inquiring person to contact the center.

Do not wait until the last moment (e.g. when you depart for a cruise) for asking us the information you need: station diagrams can only reach you by mail, in many cases.

2.2. G-Value at Base Stations

Treated as above.

2.3. Mean Anomalies, Mean Geoid Heights, Mean Values of Topography

The geographic area must be specified (polygon). According to the data set required, the request may be forwarded in some cases to the agency which computed the set.

2.4. Gravity Maps

Request them by number (from the catalogue), area, country, type (free-air, Bouguer...), scale, author, or any combination of these.

Whenever available in stock, copies will be sent without extra charges (with respect to usual cost - see § 3.3.2.). If not, two procedures can be used:

- we can make (poor quality) black and white (or ozalide-type) copies at low cost,

- color copies can be made (at high cost) if the user wishes so (after we obtain the authorization of the editor).

The cost will depend on the map, type of work, size, etc... In both cases, the user will also be asked to send his request to the editor of the map before we proceed to copying.

2.5. Gravity Measurements

BGI is now using the ORACLE Data Base Management System. One implication is that data are stored in only one format (though different for land and marine data), and that archive files do not exist anymore.

There are two distinct formats for land or sea gravity data, respectively EOL and EOS.

EOL
LAND DATA FORMAT
RECORD DESCRIPTION
126 characters

Col. 1-8 B.G.I. source number (8 char.)
9-16 Latitude (unit : 0.00001 degree) (8 char.)
17-25 Longitude (unit : 0.00001 degree) (9 char.)
26-27 Accuracy of position (2 char.)
The site of the gravity measurements is defined in a circle of radius R
0 = no information
1 - R <= 5 Meters
2 = 5 < R <= 20 M (approximately 0'01)
3 = 20 < R <= 100 M
4 = 100 < R <= 200 M (approximately 0'1)
5 = 200 < R <= 500 M
6 = 500 < R <= 1000 M
7 = 1000 < R <= 2000 M (approximately 1')
8 = 2000 < R <= 5000 M
9 = 5000 M < R
10...

28-29 System of positioning (2 char.)
0 = no information
1 = topographical map
2 = trigonometric positioning
3 = satellite

30 Type of observation (1 char.)
1 = current observation of detail or other observations of a 3rd or 4th order network
2 = observation of a 2nd order national network
3 = observation of a 1st order national network
4 = observation being part of a nation calibration line
5 = coastal ordinary observation (Harbour, Bay, Sea-side...)
6 = harbour base station

31-38 Elevation of the station (unit : centimeter) (8 char.)
39-40 Elevation type (2 char.)
1 = Land
2 = Subsurface
3 = Lake surface (above sea level)
4 = Lake bottom (above sea level)
5 = Lake bottom (below sea level)
6 = Lake surface (above sea level with lake bottom below sea level)
7 = Lake surface (below sea level)
8 = Lake bottom (surface below sea level)
9 = Ice cap (bottom below sea level)
10 = Ice cap (bottom above sea level)
11 = Ice cap (no information about ice thickness)

41-42 Accuracy of elevation (2 char.)
0 = no information
1 = E <= 0.02 M
2 = .02 < E <= 0.1 M
3 = .1 < E <= 1
4 = 1 < E <= 2
5 = 2 < E <= 5
6 = 5 < E <= 10
7 = 10 < E <= 20
8 = 20 < E <= 50
9 = 50 < E <= 100
10 = E superior to 100 M

43-44 Determination of the elevation (2 char.)
0 = no information
1 = geometrical levelling (bench mark)
2 = barometrical levelling
3 = trigonometric levelling
4 = data obtained from topographical map
5 = data directly appreciated from the mean sea level
6 = data measured by the depression of the horizon
7 = satellite

45-52 Supplemental elevation (unit : centimeter) (8 char.)
53-61 **Observed gravity** (unit : microgal) (9 char.)

62-67	**Free air anomaly** (0.01 mgal)	(6 char.)
68-73	**Bouguer anomaly** (0.01 mgal) Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	(6 char.)
74-76	Estimation standard deviation free-air anomaly (0.1 mgal)	(3 char.)
77-79	Estimation standard deviation bouguer anomaly (0.1 mgal)	(3 char.)
80-85	**Terrain correction** (0.01 mgal) *computed according to the next mentioned radius & density*	(6 char.)
86-87	Information about terrain correction 0 = no topographic correction 1 = tc computed for a radius of 5 km (zone H) 2 = tc computed for a radius of 30 km (zone L) 3 = tc computed for a radius of 100 km (zone N) 4 = tc computed for a radius of 167 km (zone 02) 11 = tc computed from 1 km to 167 km 12 = tc computed from 2.5 km to 167 km 13 = tc computed from 5.2 km to 167 km 14 =tc (unknown radius) 15 = tc computed to zone M (22 km) 16 = tc computed to zone G 17 = tc computed to zone K (18.8 km) 25 = tc computed to 48.6 km on a curved Earth 26 = tc computed to 64. km on a curved Earth	(2 char.)
88-91	Density used for terrain correction	(4 char.)
92-93	Accuracy of gravity 0 = no information 1 = E <= 0.01 mgal 2 = .01 < E <= 0.05 mgal 3 = .05 < E <= 0.1 mgal 4 = 0.1 < E <= 0.5 mgal 5 = 0.5 < E <= 1. mgal 6 = 1. < E <= 3. mgal 7 = 3. < E <= 5. mgal 8 = 5. < E <= 10 mgal 9 = 10. < E <= 15. mgal 10 = 15. < E <= 20. mgal 11 = 20. < E mgal	(2 char.)
94-99	Correction of observed gravity (unit : microgal)	(6 char.)
100-105	**Reference station** *This station is the base station (BGI number) to which the concerned station is referred*	(6 char.)

106-108	Apparatus used for the measurement of G	(3 char.)
	0.. no information 1.. pendulum apparatus before 1960 2.. latest pendulum apparatus (after 1960) 3.. gravimeters for ground measurements in which the variations of G are equilibrated of detected using the following methods : 30 = torsion balance (Thyssen...) 31 = elastic rod 32 = bifilar system 34 = Boliden (Sweden) 4.. Metal spring gravimeters for ground measurements 41 = Frost 42 = Askania (GS-4-9-11-12), Graf 43 = Gulf, Hoyt (helical spring) 44 = North American 45 = Western 47 = Lacoste-Romberg 48 = Lacoste-Romberg, Model D (microgravimeter) 5.. Quartz spring gravimeter for ground measurements 51 = Norgaard 52 = GAE-3 53 = Worden ordinary 54 = Worden (additional thermostat 55 = Worden worldwide 56 = Cak 57 = Canadian gravity meter, sharpe 58 = GAG-2 59 = SCINTREX CG2 6.. Gravimeters for under water measurements (at the bottom of the sea or of a lake) 60 = Gulf 62 = Western 63 = North American 64 = Lacoste-Romberg	
109-111	**Country code** (BGI)	(3 char.)
112	**Confidentiality** 0 = without restriction .....1 = with authorization 2 = classified	(1 char.)
113	**Validity** 0 = no validation 1 = good 2 = doubtful 3 = lapsed	(1 char.)
114-120	Numbering of the station (original)	(7 char.)
121-126	Sequence number	(6 char.)

EOS
SEA DATA FORMAT
RECORD DESCRIPTION
146 characters

Col. 1-8 **B.G.I.** source number (8 char.)

9-16 **Latitude** (unit : 0.00001 degree) (8 char.)

17-25 **Longitude** (unit : 0.00001 degree) (9 char.)

26-27 Accuracy of position (2 char.)

The site of the gravity measurements is defined in a circle of radius R

- 0 = no information
- 1 - R <= 5 Meters
- 2 = 5 < R <= 20 M (approximately 0'01)
- 3 = 20 < R <= 100 M
- 4 = 100 < R <= 200 M (approximately 0'1)
- 5 = 200 < R <= 500 M
- 6 = 500 < R <= 1000 M
- 7 = 1000 < R <= 2000 M (approximately 1')
- 8 = 2000 < R <= 5000 M
- 9 = 5000 M < R
- 10...

28-29 System of positioning (2 char.)

- 0 = no information
- 1 = Decca
- 2 = visual observation
- 3 = radar
- 4 = loran A
- 5 = loran C
- 6 = omega or VLF
- 7 = satellite
- 8 = solar/stellar (with sextant)

30 Type of observation (1 char.)

- 1 = individual observation at sea
- 2 = mean observation at sea obtained from a continuous recording

31-38 **Elevation of the station** (unit : centimeter) (8 char.)

39-40 Elevation type (2 char.)

- 1 = ocean surface
- 2 = ocean submerged
- 3 = ocean bottom

41-42 Accuracy of elevation (2 char.)

- 0 = no information
- 1 = E <= 0.02 Meter
- 2 = .02 < E <= 0.1 M
- 3 = .1 < E <= 1
- 4 = 1 < E <= 2
- 5 = 2 < E <= 5
- 6 = 5 < E <= 10
- 7 = 10 < E <= 20
- 8 = 20 < E <= 50
- 9 = 50 < E <= 100
- 10 = E superior to 100 Meters

43-44 Determination of the elevation (2 char.)

- 0 = no information
- 1 = depth obtained with a cable (meters)
- 2 = manometer depth
- 3 = corrected acoustic depth (corrected from Mathew's tables, 1939)
- 4 = acoustic depth without correction obtained with sound speed 1500 M/sec. (or 820 fathom/sec)
- 5 = acoustic depth obtained with sound speed 1463 M/sec (800 fathom/sec)
- 6 = depth interpolated on a magnetic record
- 7 = depth interpolated on a chart

45-52 Supplemental elevation (8 char.)

53-61 **Observed gravity** (unit : microgal) (9 char.)

62-67 **Free air anomaly** (0.01 mgal) (6 char.)

68-73 **Bouguer anomaly** (0.01 mgal) (6 char.)

Simple Bouguer anomaly with a mean density of 2.67. No terrain correction

74-76 Estimation standard deviation free-air anomaly (0.1 mgal) (3 char.)

77-79	Estimation standard deviation bouguer anomaly (0.1 mgal)	(3 char.)
80-85	**Terrain correction** (0.01 mgal)	(6 char.)
	computed according to the next mentioned radius & density	
86-87	Information about terrain correction	(2 char.)
	0 = no topographic correction	
	1 = tc computed for a radius of 5 km (zone H)	
	2 = tc computed for a radius of 30 km (zone L)	
	3 = tc computed for a radius of 100 km (zone N)	
	4 = tc computed for a radius of 167 km (zone 02)	
	11 = tc computed from 1 km to 167 km	
	12 = tc computed from 2.5 km to 167 km	
	13 = tc computed from 5.2 km to 167 km	
	14 =tc (unknown radius)	
	15 = tc computed to zone M (22 km)	
	16 = tc computed to zone G	
	17 = tc computed to zone K (18.8 km)	
	25 = tc computed to 48.6 km on a curved Earth	
	26 = tc computed to 64. km on a curved Earth	
88-91	Density used for terrain correction	(4 char.)
92-93	Mathew's zone	(2 char.)
	when the depth is not corrected depth, this information is necessary. For example : zone 50 for the Eastern Mediterranean Sea	
94-95	Accuracy of gravity	(2 char.)
	0 = no information	
	1 = E <= 0.01 mgal	
	2 = .01 < E <= 0.05 mgal	
	3 = .05 < E <= 0.1 mgal	
	4 = 0.1 < E <= 0.5 mgal	
	5 = 0.5 < E <= 1. mgal	
	6 = 1. < E <= 3. mgal	
	7 = 3. < E <= 5. mgal	
	8 = 5. < E <= 10. mgal	
	9 = 10. < E <= 15. mgal	
	10 = 15 < E <= 20. mgal	
	11 = 20. < E mgal	
96-101	Correction of observed gravity (unit : microgal)	(6 char.)
102-110	Date of observation	(9 char.)
	in Julian day - 2 400 000 (unit : 1/10 000 of day)	
111-113	Velocity of the ship (0.1 knot)	(3 char.)
114-118	Eötvös correction (0.1 mgal)	(5 char.)
119-121	**Country code** (BGI)	(3 char.)
122	**Confidentiality**	(1 char.)
	0 = without restriction	
	1 = with authorization	
	2 = classified	
123	**Validity**	(1 char.)
	0 = no validation	
	1 = good	
	2 = doubtful	
	3 = lapsed	
124-130	Numbering of the station (original)	(7 char.)
131-136	**Sequence number**	(6 char.)
137-139	**Leg number**	(3 char.)
140-145	**Reference station**	(6 char.)

Whenever given, the theoretical gravity (γ_o), free-air anomaly (FA), Bouguer anomaly (BO) are computed in the 1967 geodetic reference system.

The approximation of the closed form of the 1967 gravity formula is used for theoretical gravity at sea level :

$$\gamma_o = 978031.85 \times [\, 1 + 0.005278895 * \sin^2(\phi) + 0.000023462 * \sin^4(\phi) \,] \text{, mgals}$$

where ϕ is the geographic latitude.

The formulas used in computing FA and BO are summarized below.

Formulas used in computing free-air and Bouguer anomalies

Symbols used :

g	: *observed value of gravity*
γ	: *theoretical value of gravity (on the ellipsoid)*
Γ	: *vertical gradient of gravity (approximated by 0.3086 mgal/meter)*
H	: *elevation of the p ysical surface of the land, lake or glacier (H = o at sea surface), positive upward*
D_1	: *depth of water, or ice, positive downward*
D_2	: *depth of a gravimeter measuring in a mine, in a lake, or in an ocean, counted from the surface , positive downward*
G	: *gravitational constant (667.2 10^{-13} m^3 kg^{-1} s^{-2}) $\Rightarrow k = 2\pi G$*
ρ_c	: *mean density of the Earth's crust (taken as 2670 kg m^{-3})*
ρ_w^f	: *density of fresh water (1000 kg m^{-3})*
ρ_w^s	: *density of salted water (1027 kg m^{-3})*
ρ_i	: *density of ice (917 kg m^{-3})*
FA	: *free-air anomaly*
BO	: *Bouguer anomaly*

Formulas :

* *FA : The principle is to compare the gravity of the Earth at its surface with the normal gravity, which first requires in some cases to derive the surface value from the measured value. Then, and until now, FA is the difference between this Earth's gravity value reduced to the geoid and the normal gravity γ_0 computed on the reference ellipsoid (classical concept). The more modern concept *, in which the gravity anomaly is the difference between the gravity at the surface point and the normal (ellipsoidal) gravity on the telluroid corresponding point may be adopted in the future depending on other major changes in the BGI data base and data management system.*

* *BO : The basic principle is to remove from the surface gravity the gravitational attraction of one (or several) infinite plate (s) with density depending on where the plate is with respect to the geoid. The conventional computation of BO assumes that parts below the geoid are to be filled with crustal material of density ρ_c and that the parts above the geoid have the density of the existing material (which is removed).*

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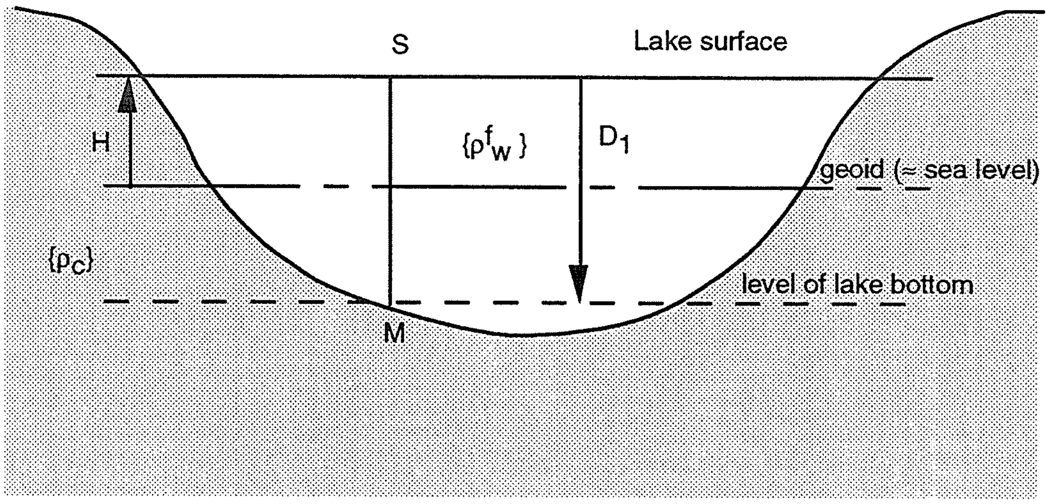
* cf. "On the definition and numerical computation of free air gravity anomalies", by H.G. Wenzel. Bulletin d'Information, BGI, n° 64, pp. 23-40, June 1989.

For example, if a measurement g_M is taken at the bottom of a lake, with the bottom being below sea level, we have :



$$g_S = g_M + 2\,k\,\rho^f_W\,D_1 - \Gamma D_1$$
$$\Rightarrow FA = g_S + \Gamma H - \gamma_o$$

Removing the (actual or virtual) topographic masses as said above, we find :

$$\begin{aligned}\delta g_s &= g_s - k\,\rho^f_w\,D_1 + k\,\rho_c(D_1 - H)\\ &= g_s - k\,\rho^f_w\,[H + (D_1 - H)] + k\,\rho_c\,(D_1 - H)\\ &= g_s - k\,\rho^f_w\,H + k\,(\rho_c - \rho^f_w)(D_1 - H)\end{aligned}$$

$$\Rightarrow \quad BO = \delta g_s + \Gamma\,H - \gamma_o$$

The table below covers most frequent cases. It is an update of the list of formulas published before, where four typing errors have been corrected.

It may be noted that, although some formulas look different, they give the same results. For instance BO (C) and BO (D) are identical since :

$$\begin{aligned}-k\,\rho_i H + k(\rho_c - \rho_i)(D_1 - H) &\equiv -k\,\rho_i(H - D_1 + D_1) - k(\rho_c - \rho_i)(H - D_1)\\ &\equiv -k\,\rho_i\,D_1 - k\,\rho_c(H - D_1)\end{aligned}$$

Similarly, BO (6), BO (7) and BO (8) are identical.

Elev. Type	Situation	Formulas
1	Land Observation-surface	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_C H$
2	Land Observation-subsurface	$FA = g + 2 k \rho_C D_2 + \Gamma (H - D_2) - \gamma_0$ $BO = FA - k \rho_C H$
3	Ocean Surface	$FA = g - \gamma_0$ $BO = FA + k (\rho_C - \rho_w^s) D_1$
4	Ocean submerged	$FA = g + (2 k \rho_w^s - \Gamma) D_2 - \gamma_0$ $BO = FA + k (\rho_C - \rho_w^s) D_1$
5	Ocean bottom	$FA = g + (2 k \rho_w^s - \Gamma) D_1 - \gamma_0$ $BO = FA + k (\rho_C - \rho_w^s) D_1$
6	Lake surface above sea level with bottom above sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_w^f D_1 - k \rho_C (H - D_1)$
7	Lake bottom, above sea level	$FA = g + 2 k \rho_w^f D_1 + \Gamma (H - D_1) - \gamma_0$ $BO = FA - k \rho_w^f D_1 - k \rho_C (H - D_1)$
8	Lake bottom, below sea level	$FA = g + 2 k \rho_w^f D_1 + \Gamma (H - D_1) - \gamma_0$ $BO = FA - k \rho_w^f H + k (\rho_C - \rho_w^f)(D_1 - H)$
9	Lake surface above sea level with bottom below sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_w^f H + k (\rho_C - \rho_w^f)(D_1 - H)$
A	Lake surface, below sea level (here $H < o$)	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_C H + k (\rho_C - \rho_w^f) D_1$
B	Lake bottom, with surface below sea level ($H < o$)	$FA = g + (2 k \rho_w^f - \Gamma) D_1 + \Gamma H - \gamma_0$ $BO = FA - k \rho_C H + k (\rho_C - \rho_w^f) D_1$
C	Ice cap surface, with bottom below sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_i H + k (\rho_C - \rho_i)(D_1 - H)$
D	Ice cap surface, with bottom above sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_i D_1 - k \rho_C (H - D_1)$

2.6 Satellite Altimetry Data

BGI has access to the Geos 3, Seasat and Geosat data bases which are managed by the Groupe de Recherches de Géodésie Spatiale (GRGS). These data are now in the public domain.

Since January 1, 1987, the following procedure has been applied :

(a) Requests for satellite altimetry derived geoid heights (N), that is : time (julian date), longitude, latitude, N, are processed by BGI. for small areas (smaller than 20° x 20°), and forwarded to GRGS for larger areas.

(b) Requests for the full altimeter measurements records are forwarded to GRGS, or NASA in the case of massive request.

In all cases, the geographical area (polygon) and beginning and end of epoch (if necessary) should be given.

All requests for data must be sent to :

Mr. Gilles BALMA
Bureau Gravimétrique International
18, Avenue E. Belin - 31055 Toulouse Cedex - France

In case of a request made by telephone, it should be followed by a confirmation letter, or telex. Except in particular case (massive data retrieval, holidays...) requests are satisfied within one month following the reception of the written confirmation, or information are given concerning the problems encountered.

If not specified, the data will be written, formatted (EBCDIC) on labeled 9-track tape (s) with a fixed block size. for large amounts of data, or on diskette in the case of small files. The exact physical format will be indicated in each case.

3. USUAL SERVICES BGI CAN PROVIDE

The list below is not restrictive and other services (massive retrieval, special evaluation and products...) may be provided upon request.

The costs of the services listed below are a revision of the charging policy established in 1981 (and revised in 1989) in view of the categories of users : (1) contributors of measurements and scientists, (2) other individuals and private companies.

The prices given below are in french francs. They have been effective on January 1, 1992 and may be revised periodically.

3.1. Charging Policy for Data Contributors and Scientists

For these users and until further notice, - and within the limitation of our in house budget, we shall only charge the incremental cost of the services provided. In all other cases, a different charging policy might be applied.

However, and at the discretion of the Director of B.G.I., some of the services listed below may be provided free of charge upon request, to major data contributors, individuals working in universities, especially students ...

3.1.1. Digital Data Retrieval

. on one of the following media :
** printout .... 2 F/100 lines*
** diskette...................... 25 F per diskette (minimum charge : 50 F-*
** magnetic tape .... 2 F per 100 records*
+ 100 F per tape - 1600 BPI
(if the tape is not to be returned)

. minimum charge : 100 F

. maximum number of points : 100 000 ; massive data retrieval (in one or several batches) will be processed and charged on a case by case basis.

3.1.2. Data Coverage Plots : in Black and White, with Detailed Indices

. 20°x20° blocks, as shown on the next pages (maps 1 and 2) : 400 F each set.

. For any specified area (rectangular configurations delimited by meridians and parallels) : 1. F per degree square : 100 F minimum charge (at any scales, within a maximum plot size of : 90 cm x 180 cm).

. For area inside polygon : same prices as above, counting the area of the minimum rectangle comprising the polygon.

3.1.3. Data Screening

(Selection of one point per specified unit area, in decimal degrees of latitude and longitude, i.e. selection of first data point encountered in each mesh area).

. 5F/100 points to be screened.

. 100 F minimum charge.

3.1.4. Gridding

(Interpolation at regular intervals Δ in longitude and Δ' in latitude - in decimal degrees) :

. 10 F/($\Delta\Delta'$) per degree square

. minimum charge : 150 F

. maximum area : 40° x 40°

3.1.5. Contour Maps of Bouguer or Free-Air Anomalies

At a specified contour interval Δ (1, 2, 5,... mgal), on a given projection :
10 F/Δ per degree square, plus the cost of gridding (see 3.4) after agreement on grid stepsizes. (at any scale, within a maximum map size for : 90 cm x 180 cm).

. 250 F minimum charge

. maximum area : 40° x 40°

3.1.6. Computation of Mean Gravity Anomalies

(Free-air, Bouguer, isostatic) over Δ xΔ' area : 10F/ΔΔ' per degree square.

. minimum charge : 150 F

. maximum area : 40°x40°

3.2. Charging Policy for Other Individuals or Private Companies

3.2.1. Digital Data Retrieval

..1 F per measurement

. minimum charge : 150 F

3.2.2. Data Coverage Plots, in Black and White, with Detailed Indices

. 2 F per degree square ; 100 F minimum charge. (maximum plot size = 90 cm x 180 cm)

. For area inside polygon : same price as above, counting the area of the smallest rectangle comprising ihe polygon.

3.2.3. Data Screening

. 1 F per screened point

. 250 F minimum charge

3.2.4. Gridding

Same as 31.4.

3.2.5. Contour Maps of Bouguer or Free-Air Anomalies

Same as 3.1.5.

3.2.6. Computation of Mean Gravity Anomalies

Same as 3.1.6.

3.3. Gravity Maps

The pricing policy is the same for all categories of users

3.3.1. Catalogue of all Gravity Maps

Printout : 200 F

Tape 100 F (+ tape price, if not to be returned)

3.2.2. Maps

. Gravity anomaly maps (excluding those listed below) : 100 F each

. Special maps :

Mean Altitude Maps

FRANCE	*(1: 600 000)*	*1948*	*6 sheets*	*65 FF the set*
WESTERN EUROPE	*(1:2 000 000)*	*1948*	*1 sheet*	*55 FF*
NORTH AFRICA	*(1:2 000 000)*	*1950*	*2 sheets*	*60 FF the set*
MADAGASCAR	*(1:1 000 000)*	*1955*	*3 sheets*	*55 FF the set*
MADAGASCAR	*(1:2 000 000)*	*1956*	*1 sheet*	*60 FF*

Maps of Gravity Anomalies

NORTHERN FRANCE	*Isostatic anomalies*	*(1:1 000 000)*	*1954*	*55 FF*
SOUTHERN FRANCE	*Isostatic anomalies Airy 50*	*(1:1 000 000)*	*1954*	*55 FF*
EUROPE-NORTH AFRICA	*Mean Free air anomalies*	*(1:1 000 000)*	*1973*	*90 FF*

World Maps of Anomalies (with text)

PARIS-AMSTERDAM	*Bouguer anomalies*	*(1:1 000 000)*	*1959-60*	*65 FF*
BERLIN-VIENNA	*Bouguer anomalies*	*(1:1 000 000)*	*1962-63*	*55 FF*
BUDAPEST-OSLO	*Bouguer anomalies*	*(1:1 000 000)*	*1964-65*	*65 FF*
LAGHOUAT-RABAT	*Bouguer anomalies*	*(1:1 000 000)*	*1970*	*65 FF*
EUROPE-AFRICA	*Bouguer Anomalies*	*(1:10 000 000)*	*1975*	*180 FF with text* *120 FF without text*
EUROPE-AFRICA	*Bouguer anomalies-Airy 30*	*(1:10 000 000)*	*1962*	*65 FF*

Charts of Recent Sea Gravity Tracks and Surveys (1:36 000 000)

CRUISES prior to	*1970*	*65 FF*
CRUISES	*1970-1975*	*65 FF*
CRUISES	*1975-1977*	*65 FF*

Miscellaneous

CATALOGUE OF ALL GRAVITY MAPS

listing	*200 FF*
tape	*300 FF*

THE UNIFICATION OF THE GRAVITY NETS OF AFRICA

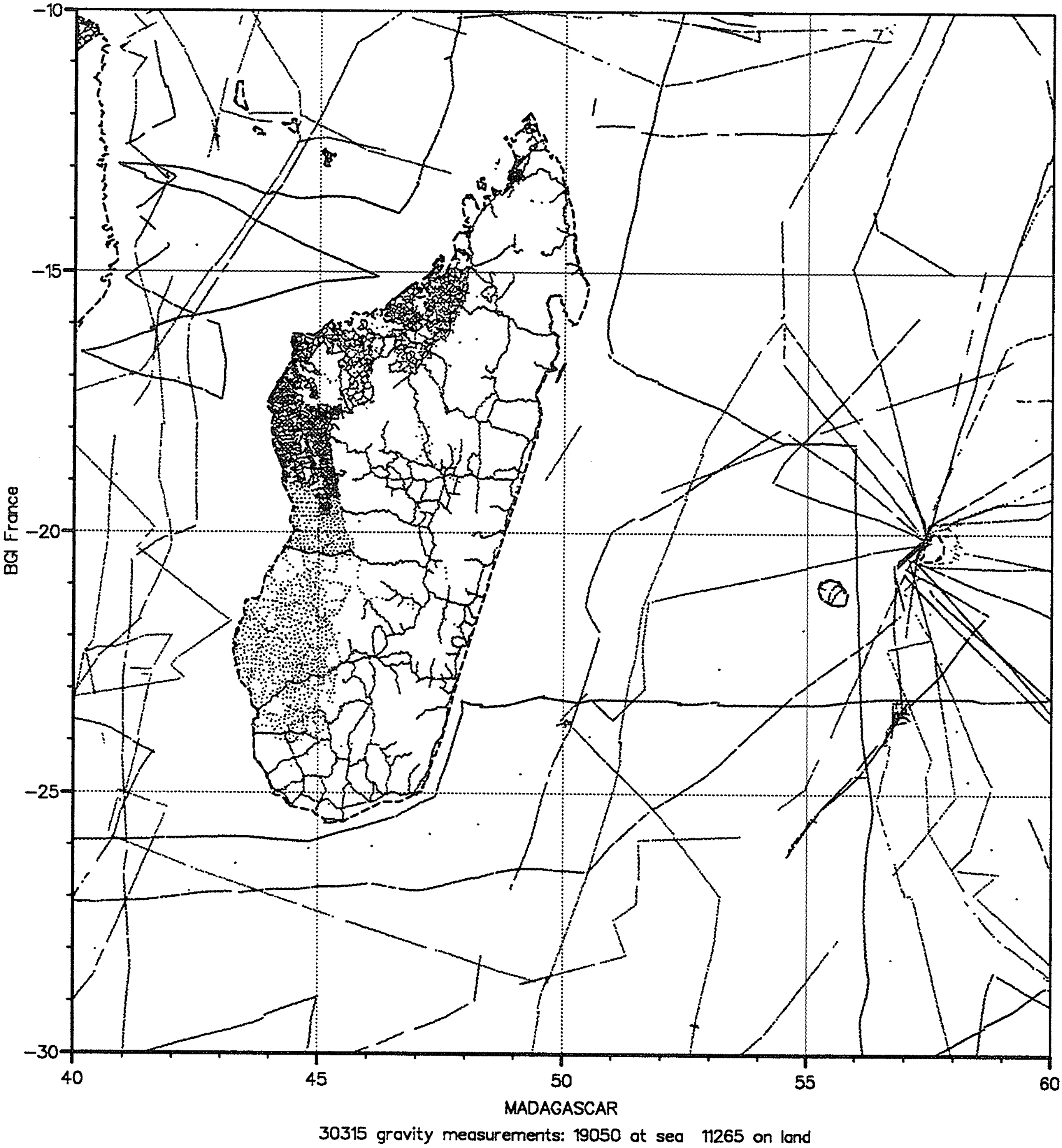
(Vol. 1 and 2) *1979* *150 FF*

. Black and white copy of maps : 150 F per copy

. Colour copy : price according to specifications of request.

Mailing charges will be added for air-mail parcels when "Air-Mail" is requested)

Map 1. Example of data coverage plot



Map 2. Example of detailed index (Data coverage corresponding to Map 1)

BGI GRAVITY DATA: MEAN FREE AIR ANOMALY

1ST FIELD: POINTS NUMBER
2ND FIELD: MEAN VALUE (MGAL)
3RD FIELD: R.M.S (MGAL**2)

-10

213 / 23.4 / 10.1	105 / -40.2 / 42.3	15 / 5.6 / 6.2	75 / -25.6 / 13.0	16 / -12.8 / 2.1	26 / -18.3 / 4.3	29 / -27.7 / 17.6	184 / -22.5 / 26.3	53 / -23.9 / 10.3	65 / -27.9 / 26.7	26 / -8.2 / 37.4	8 / -7.2 / 24.0	116 / -5.5 / 8.2	138 / -13.1 / 11.1	52 / -5.8 / 5.9	44 / -3.8 / 12.2	54 / -1.8 / 22.8	84 / -9.2 / 9.2		66 / -13.9 / 9.4
	151 / -20.4 / 32.5	41 / -15.2 / 13.2	48 / 96.1 / 132.0	64 / -18.3 / 13.8	41 / -26.4 / 3.9		85 / -42.6 / 9.9		2 / 77.7 / 2.8	13 / -45.1 / 4.8	82 / -12.9 / 16.3	43 / -7.7 / 8.4	29 / -16.9 / 4.3	2 / -8.1 / 1.3	25 / -2.6 / 13.6	67 / -14.4 / 10.5	40 / -1.7 / 2.6		37 / -21.3 / 5.9
21 / -55.9 / 5.6	257 / -42.7 / 17.2	51 / -63.4 / 12.2	27 / 129.1 / 219.8	121 / 21.1 / 166.0	72 / 85.1 / 158.0	32 / -47.1 / 3.7	100 / -57.9 / 6.1	15 / 37.2 / 9.1	111 / 54.8 / 17.3	15 / -32.7 / 1.7	101 / -17.2 / 4.5	26 / -12.3 / 6.0	26 / -20.4 / 5.9	35 / -23.8 / 3.1	58 / -11.0 / 13.1	50 / -8.6 / 10.1	6 / -6.1 / 1.4		16 / 58.7 / 4.8
3 / -47.8 / 1.6	375 / -13.6 / 29.9	170 / -40.3 / 11.7	223 / -39.3 / 8.4	134 / -52.4 / 4.7	85 / -40.1 / 5.7	171 / -38.5 / 8.0	34 / -31.5 / 38.1	154 / 29.6 / 16.7	117 / 34.3 / 15.9	4 / 82.6 / 10.5	72 / -5.9 / 3.5			23 / -.2 / 6.7	1 / 21.7 / 0.0	49 / -4.5 / 5.5			63 / 11.3 / 54.6
	284 / 3.6 / 77.8	24 / -35.7 / 3.3	108 / -27.8 / 4.3	84 / -36.3 / 7.6	97 / -42.4 / 5.2		87 / -13.1 / 12.8	101 / 1.2 / 32.6	44 / 12.3 / 16.4	60 / 47.6 / 20.2	71 / -10.8 / 4.5			31 / -8.6 / 4.7	11 / 11.9 / 4.2	62 / 3.7 / 7.3	41 / -.8 / 11.4	3 / 12.3 / .4	49 / -39.7 / 10.8
1 / -45.2 / 0.0	247 / -45.1 / 42.5	575 / -22.2 / 13.1	396 / -63.3 / 8.2	151 / -72.8 / 25.2	103 / -63.6 / 32.4	322 / -12.4 / 14.3	612 / -18.5 / 9.7	145 / -4.9 / 10.3	38 / -36.5 / 6.8	47 / 1.3 / 28.1	35 / -27.3 / 2.4			42 / 28.9 / 53.0	6 / 1.4 / 1.6	32 / 8.8 / 10.7	9 / -7.4 / 3.3	68 / -17.7 / 17.1	7 / -33.3 / 3.0
102 / -20.1 / 14.1	480 / -47.1 / 41.9	159 / -40.4 / 15.9	175 / -25.5 / 10.5	346 / 12.6 / 19.8	414 / -5.1 / 15.2	407 / -26.0 / 8.9	240 / -3.1 / 12.8	53 / 50.4 / 19.5	117 / .3 / 20.4	45 / -15.8 / 12.2	51 / -14.9 / 11.7		30 / -16.8 / 3.8	84 / -14.0 / 14.9	28 / -9.5 / 16.2	73 / 4.9 / 9.3	6 / -18.4 / 2.5	95 / -.0 / 19.4	31 / 57.7 / 50.5
44 / -7.9 / 13.0	105 / -42.2 / 35.5	98 / -4.4 / 28.1	136 / -18.1 / 12.5	774 / 6.0 / 24.4	384 / 8.1 / 17.6	83 / -10.4 / 22.3	76 / 50.3 / 33.1	110 / 35.0 / 20.6	66 / 15.9 / 19.4	3 / -43.9 / 2.1	27 / -16.8 / 4.3	79 / -2.1 / 6.9	133 / -2.2 / 5.9	14 / 3.4 / 5.2	146 / -10.3 / 11.5	68 / -8.6 / 19.3	28 / -19.8 / 10.5	98 / -2.5 / 41.4	23 / 39.5 / 30.2
67 / -40.4 / 6.8	46 / -26.6 / 29.7	32 / 21.1 / 12.5		720 / -7.5 / 11.7	380 / -9.3 / 34.2	154 / 46.3 / 12.9	202 / 62.1 / 16.1	137 / 23.2 / 25.1	90 / 18.5 / 32.6	13 / -47.8 / 3.0		74 / -5.0 / 6.9	71 / -8.1 / 6.1	167 / -.3 / 11.8	198 / -5.1 / 14.1	114 / -34.1 / 14.2	59 / 25.1 / 50.0	23 / 36.9 / 59.0	34 / -.3 / 25.8
47 / -42.2 / 7.9	92 / -44.9 / 15.2	38 / 16.8 / 19.8		176 / -20.1 / 10.0	330 / -23.5 / 19.8	115 / 40.8 / 20.0	171 / 67.2 / 18.7	91 / 31.8 / 26.5	2 / 56.5 / 2.1	2 / -9.8 / 1.1	37 / -13.3 / 3.7	100 / -5.7 / 8.9		26 / -13.0 / 5.3	97 / -25.9 / 8.9	114 / -59.6 / 24.4	262 / 69.9 / 102.5	105 / -14.7 / 72.2	66 / 4.5 / 27.9
24 / -22.6 / 7.4	152 / -23.3 / 14.5	17 / -33.2 / 15.0	6 / 4.3 / 2.3	151 / 5.1 / 28.1	142 / -15.2 / 27.6	49 / 49.4 / 27.5	104 / 49.6 / 22.1	81 / 47.0 / 39.1		43 / -21.3 / 7.3	24 / -2.9 / 8.8	24 / -.8 / 15.1	23 / -3.7 / 15.9	24 / 8.8 / 23.7	47 / 149.9 / 98.1	153 / -24.5 / 32.5	368 / 8.6 / 70.6	96 / -33.1 / 28.0	53 / -.2 / 16.3
26 / -24.4 / 8.6	105 / -11.3 / 9.0	58 / -15.3 / 19.9	97 / 12.4 / 12.2	166 / -2.7 / 14.8	81 / -4.2 / 20.1	146 / 26.4 / 16.7	176 / -5.8 / 33.8	99 / 46.9 / 39.3		52 / -24.8 / 5.7	77 / 5.1 / 5.9	24 / -5.5 / 1.2	8 / -18.5 / 4.5	1 / 13.0 / 0.0	65 / 281.3 / 61.4	202 / -6.8 / 50.2	210 / -29.2 / 24.2	170 / -2.4 / 16.1	44 / 16.5 / 9.0
184 / 7.6 / 29.5	147 / 3.4 / 11.4	60 / -20.0 / 11.0	113 / 30.0 / 12.9	200 / 17.6 / 16.0	165 / 41.9 / 30.9	150 / 29.2 / 19.1	203 / 7.3 / 34.4	13 / 75.7 / 3.6		45 / -14.0 / 1.7	73 / -5.2 / 11.8		1 / 1.6 / 0.0	5 / -2.8 / 1.0	51 / -14.3 / 4.4	186 / -9.7 / 11.9	100 / -15.0 / 24.7	106 / -.8 / 14.4	108 / 9.4 / 14.1
155 / -3.1 / 10.5	59 / 5.2 / 7.9		76 / 27.0 / 12.3	236 / 11.5 / 23.4	118 / 31.8 / 14.8	46 / 36.0 / 17.4	157 / 32.3 / 29.4	145 / -7.5 / 6.2	116 / -2.8 / 7.5	214 / -25.0 / 13.6	185 / 7.5 / 10.3	105 / 21.2 / 16.0	76 / 5.2 / 3.5	97 / 11.1 / 7.2	104 / 6.4 / 30.2	295 / 9.1 / 9.6	165 / -8.7 / 26.1	87 / 2.6 / 10.0	124 / -8.0 / 14.1
33 / -3.4 / 5.9	126 / 6.2 / 17.3		28 / 39.4 / 10.6	132 / 50.4 / 10.8	151 / 30.1 / 9.7	138 / 10.8 / 34.4	131 / 27.0 / 42.3		34 / -7.5 / 4.0	17 / -16.5 / 3.6	76 / 4.3 / 5.6	27 / 3.7 / 3.8	27 / 1.6 / 9.3	12 / 43.2 / 3.2	61 / 7.9 / 16.7	173 / 5.9 / 10.7	41 / -21.1 / 25.3	29 / -12.5 / 17.2	
134 / -7.5 / 9.6	167 / -.5 / 10.0	58 / 3.7 / 7.0	58 / 1.2 / 14.4	104 / 19.5 / 32.7	161 / 11.4 / 28.4	122 / 41.7 / 41.0	31 / 66.7 / 19.1	1 / -24.9 / 0.0	45 / -12.2 / 6.2	48 / -1.2 / 7.3	76 / -3.1 / 8.1	70 / 6.4 / 7.9	26 / 14.3 / 3.2	53 / 8.5 / 26.3	70 / -8.9 / 3.7	100 / 6.4 / 4.0	47 / -3.7 / 18.7	26 / -8.1 / 2.9	24 / -6.5 / 9.6
37 / -27.9 / 4.9	126 / 16.8 / 22.3	69 / 4.8 / 10.3	71 / -8.9 / 22.0	37 / -22.3 / 20.2	37 / -7.4 / 6.9	30 / -6.7 / 10.4	35 / -7.5 / 5.9	48 / -20.5 / 7.6	71 / -16.2 / 4.7	93 / -10.1 / 6.3	52 / -6.6 / 3.7	21 / -11.9 / 5.8	9 / -9.7 / 1.1	15 / -17.9 / 4.5		105 / 2.1 / 7.7	27 / 9.8 / 22.6	56 / -8.2 / 9.4	13 / -18.2 / 7.4
75 / -9.5 / 14.8	81 / 2.7 / 18.8	3 / -5.7 / .5		35 / 11.6 / 20.6	40 / 42.6 / 10.4	60 / 59.5 / 22.8	14 / 36.7 / 10.5		6 / 2.5 / 1.1	42 / -1.4 / 4.2	56 / 1.1 / 10.2		25 / -11.6 / 4.2		4 / -8.9 / 2.6	78 / 6.7 / 3.3	24 / 1.5 / 3.2	34 / -29.5 / 21.5	27 / -.1 / 17.3
63 / -24.0 / 7.8	34 / -14.1 / 4.9			12 / 10.7 / 4.8	1 / 6.2 / 0.0		28 / 39.8 / 6.4	79 / 38.0 / 15.9	134 / 14.6 / 6.7	38 / -3.0 / 3.9	20 / -6.6 / 11.8	17 / 8.6 / 4.4	6 / -3.2 / 1.9	16 / -12.0 / 5.3	18 / -.8 / 3.1	115 / -3.5 / 10.0	29 / -3.6 / 19.9	29 / 1.2 / 15.2	108 / 12.4 / 20.6
	55 / -13.2 / 8.3	31 / 3.9 / 3.9	33 / -6.1 / 16.4	64 / 16.1 / 17.5	9 / 47.1 / 22.8	21 / 20.3 / 17.2	40 / 11.7 / 4.6	3 / 7.7 / .4	48 / 23.0 / 12.0			37 / 16.7 / 8.0	11 / -6.2 / 4.8	23 / -5.6 / 3.8		88 / .1 / 7.2	57 / .6 / 20.7	111 / 1.4 / 17.5	36 / 20.6 / 8.7

-20 (between rows 10 and 11)

-30

40 50 60

4. PROVIDING DATA TO B.G.I.

4.1. Essential Quantities and Information for Gravity Data Submission

1. Position of the site :

- *latitude, longitude (to the best possible accuracy),*
- *elevation or depth :*
  . for land data : elevation of the site (on the physical surface of the Earth) *
  . for water stations : water depth.

2. Measured (observed) gravity, corrected to eliminate the periodic gravitational effects of the Sun and Moon, and the instrument drift **

3. Reference (base) station (s) used. For each reference station (a site occupied in the survey where a previously determined gravity value is available and used to help establish datum and scale for the survey), give name, reference station number (if known), brief description of location of site, and the reference gravity value used for that station. Give the datum of the reference value ; example : IGSN 71.

4.2. Optional Information

The information listed below would be useful, if available. However, none of this information is mandatory.

. Instrumental accuracy :

- *identify gravimeter (s) used in the survey. Give manufacturer, model, and serial number, calibration factor (s) used, and method of determining the calibration factor (s).*

- *give estimate of the accuracy of measured (observed) gravity. Explain how accuracy value was determined.*

. Positioning accuracy :

- *identify method used to determine the position of each gravity measurement site.*

- *estimate accuracy of gravity station positions. Explain how estimate was obtained.*

- *identify the method used to determine the elevation of each gravity measurement site.*

- *estimate accuracy of elevation. Explain how estimate was obtained. Provide supplementary information, for elevation with respect to the Earth's surface or for water depth, when appropriate.*

. Miscellaneous information :

- *general description of the survey.*
  date of survey : organization and/or party conducting survey.
- *if appropriate : name of ship, identification of cruise.*
- *if possible, Eötvös correction for marine data.*

. Terrain correction

Please provide brief description of method used, specify : radius of area included in computation, rock density factor used and whether or not Bullard's term (curvature correction) has been applied.

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* Give supplementary elevation data for measurements made on towers, on upper floor of buildings, inside of mines or tunnels, atop glacial ice. When applicable, specify whether gravity value applied to actual measurement site or it has been reduced to the Earth's physical surface (surface topography or water surface)
Also give depth of actual measurement site below the water surface for underwater measurements.
** For marine gravity stations, gravity value should be corrected to eliminate effects of ship motion, or this effect should be provided and clearly explained.

. Isostatic gravity

Please specify type of isostatic anomaly computed.
Example : Airy-Heiskanen, T = 30 km.

. Description of geological setting of each site

4.3. Formats

Actually, any format is acceptable as soon as the essential quantities listed in 4.1. are present, and provided that the contributor gives satisfactory explanations in order to interpret his data properly.

The contributor may use, if he wishes so, the BGI Official Data Exchange Format established by BRGM in 1976 : "Progress Report for the Creation of a Worldwide Gravimetric Data Bank", published in BGI Bull. Info, n° 39, and recalled in Bulletin n° 50 (pages 112-113).

If magnetifc tapes are used, contributors are kindly asked to use 1600 bpi, unlabelled tapes (if possible), with no password, and formatted records of possibly fixed length and a fixed blocksize, too. Tapes are returned whenever specified, as soon as they are copied

PART II

DIRECTING BOARD

Toulouse Oct. 26, 1992

Activity Report for the period Aug. 91 - Sept. 92

The office continues to operate in Toulouse, where it has been located since 1980. It is supported by five national organisations : the Centre National d'Etudes Spatiales (C.N.E.S.), the Centre National de la Recherche Scientifique (C.N.R.S.), the Institut Géographique National (I.G.N.), the Institut National des Sciences de l'Univers (I.N.S.U.) and the Bureau de Recherches Géologiques et Minières (B.R.G.M.).

B.G.I. continues its data collection activities especially in the framework of large regional projects, in order to densify the world data coverage, and has put emphasis on the validation of received measurements, so as to improve the quality of the delivered information.

In Geodesy, gravity values play a great part in the modeling of the Earth gravity field, which is of permanent use for the computation of precise satellite orbits. It is also an essential information for the definition of the ocean mean surface used for the study of the global circulation.

In Geophysics, the interpretation of the gravity field anomalies allows to study density variations in the lithosphere or the mantle, with applications in oil and mineral prospecting.

1. SERVICE ACTIVITIES

1.1. Data Base Software Development

Instead of putting more efforts from BGI staff and following the availability of the ORACLE software on a main frame IBM 4381 at CNES, it was decided in early 1991 and after extensive satisfactory testing to discontinue the usage of the old software (which was running on CDC Cybers) and to switch to ORACLE (level 6). A first version was operational in the fall of 1991. Attention was exerted to ensure no interruption in the services; for this purpose, the two software with two different data bases have been run and used in parallel up to early 1992 until not a single failure appears with the new system.

1.2. Data Collection

The data base content, as concerns actual measurements, is regularly increasing. It contains a little more than four and a half million point gravity values in about 3000 sources. It still remains several sets of land data to be added. This has been a very slow process due to the characteristics of the old CDC software, until the new system was perfectly working. Large data sets of marine data were received from NGDC in the context of the European Geoid Project and, recently, we acquired the totality of the NGDC data on CD-Rom. These will be processed and merged in the course of 1993.

New catalogues will be produced (last update: August, 1991) at the end of this year - availability on request :

. General coverage of gravity data per 20 x 20 degrees area

. Index catalogue of data distribution: statistics per degree square, mean value, standard deviation.

In addition, efforts were exerted in trying to get data from the ex-Eastern countries. In most cases, gridded values of free-air gravity and topography were obtained such as in Poland (5' x 5'), Hungary (5' x 7.5'), Rumania (5' x 5').

1.3. Data Validation

A special effort, which requested about one man-year work, was undertaken to convert the VERSET/DIVA land data validation software on a SUN-Sparc 2 workstation using the SUNPHIGS library, allowing future portability and (possibly) easier upgrading.

After all land data had been validated on a oneby one source basis using the validation tools developed in house (SYSTEVAL, VERSET/DIVA), concern was given to intercompare overlapping sources. The software is in its last phase of development. Plans are now made to install similar software for the validation of marine data especially to solve for cross-over minimization parameters. A program (SEAGRA) for performing this task, was received from H.G. Wenzell. It was installed, upgraded; in particular, the decomposition of each cruise into legs has been implemented in an automatic mode in late 1991. A complete tool in its first version is available and will be presented at the workshop organised on these topics (Oct. 27-28,1992).

1.4. Requests

The bureau has received and satisfied 175 requests for data and services in 1991 and 194 requests in the time period covered by this report. This corresponds to a mean increase of ≈160 % with respect to the last four year period of time (3 % with respect to 1991). This activity presently employs one person more than half-time.

1.5. Bibliography

Compilation of the gravity bibliography continues. The digitization of the old bibliography, prior to 1980, undertaken in 1990, was a huge work which was performed by the BGI secretary, with an additional temporary help. It was completed in 1991. A file is available on floppy disk.

This data base is resident on hard disk on a P.C., also on the main frame IBM 4381, and managed by means of the ORACLE software, too.

1.6 Miscellaneous

- training of students: data validation procedures, graphics.

- compilation of absolute measurements : still difficult (agencies do not answer to our request for data and facts). A point for debate by the Directing Board.

status of IGSN 71 stations: unchanged (last situation was established in 1989).

- update of map file and new catalogue. A few maps were added. Software to extract information from the complete file was modified.

- update of reference station file: microfiching is done from time to time.

- preparation and realization of a Spot image map with contours of Bouguer gravity anomalies to publicize the role of BGI (with IGN Espace Company).

2. SPECIAL PROJECTS OR EVENTS

2.1. South American Gravity Project (SAGP)

BGI was involved with a group at the Leeds University in their South American gravity compilation project on the same basis as the African project in 1985-88. In addition, BGI brought its expertise and validated the initial data set (about 70 000 gravity observations) over this continent. The project terminated in June 1991, but final products were produced later, in the course of 1992 : 5' x 5' of free-air and Bouguer anomalies, and of topography ; atlas of maps. BGI is a depository of these products which are used internally, but are not freely available - except over local areas or for lower resolution data sets (e.g. 30' x 30' obtained by O.S.U.).

2.2. Other Regional Gravity ProJects

ULIS made new plans in 1990 for projects similar to the ones above mentioned, in South-East Asia (SEAGP) and in Europe, including the ex-Eastern countries and ex-USSR, up to Ural (WEEGP). BGI is also involved in these activities. Both projects started in mid 1991. Of special interest is WEEGP since it is in some way combined with the efforts of the Sub-Commission for the Geoid in Europe (of the International Commission for the Geoid). Great emphasis is put on WEEGP due to the new situation in this part of the world; specifically, Russia is going to provide gridded data at the resolution of 4 km x 4 km. SEAGP is facing insuperable problems with India and China ; Indian authorities are keeping all recent gravity data and Chinese authorities refuse to provide any kind of gravity information (apart from a poor resolution map with contour lines at 25 mgal interval).

2.3. Participation in ICL/CC5 Activlties

The Director of the Bureau continues to represent the International Gravity Commission on CC5.

2.4. Participation in RGIA

The Bureau contributes to the activities in the project : "Réseau Géodésique Intégré sur l'Afrique", in which the establishment of new gravity networks, the making of absolute measurements, and questions of data densification are discussed (M. Sarrailh is the liaison person). But no action took place in 1992.

2.5. Activities Related to Digital Terrain Models

The International Service for the Geoid and BGI have in mind to build up a data base of DTMs for a variety of uses, but obviously with major applications in geodesy and geophysics.

After a short period of excitement on the french space agency (CNES) side (one of the supporting organisations of BGI), the enthusiasm cooled down for it appears now that the CNES interest for the project is not so great or at least too diluted in something else (links with IGBP) of which the future is not so certain.

Nevertheless, it was decided to go ahead, though slowly, and to first set up a limited DTM base around the Western Mediterranean, in relationship with other projects over this area. Main activities will consist in:

- collecting existing (gridded) DTMs, probably with varied resolution.
- creating DTMs from the BGI gravity data base (height informations).
- comparing these two types of DTMs.
- providing the best possible grids over limited areas.

3. MEETINGS

- BGI participated in the European Geoid Workshop in Prague (May 1992) with the presentation of a paper ("The Data Base Management System at BGI", D. Toustou).
- BGI organised and participated in the first WEEGP-SEAGP Progress Meeting (Toulouse, Oct. 12-16, 1992) and presented four papers:

. "Data Base Management System under ORACLE" (D. Toustou)
. "The Validation of Land Gravity Data" (M. Sarrailh)
. "The Problem of Datum Shifts" (G. Balmino)
. "Satellite Data : from Altimetry Measurements to Gravity Anomalies" (G. Balmino).

4. SPECIFIC ACCOMPLISHMENTS

5' x 5' Gravity Map of the World

The Bureau and WG1 members (at GSC, Ottawa, Can.) have prepared a 5' x 5' gravity map of the whole world. BGI produced the part of the basic grid over land areas (Bouguer anomalies) while GSC prepared the oceanic part (free-air). It was published in June 1991 and widely distributed, first at the 20th. IUGG general assembly, then on the occasion of various meetings or contacts..

5. PUBLICATIONS

Bulletin d'Information :	Dec. 1991 (n° 69) June 1992 (n° 70) : contains the National Reports.
BGI holdings, Data Base Coverage :	Aug. 1991 New issue to appear in Dec. 1992.

Minutes of BGI Directing Board Meeting Oct. 26, 1992, held in Toulouse

Directing Board :	G. Balmino	(France)
	G. Boedecker	(Germany)
	N. Courtier	(Canada)
	J. Faller	(U.S.A.)
	R. Forsberg	(Denmark)
	E. Groten	(Germany)
	E. Klingele	(Switzerland)
	J. Kovalevsky	(France)
	T. Lambert	(Canada)
	J. Makinen	(Finland)
	I. Marson	(Italy)
	P.P. Medvedev	(Italy)
	C. Poitevin	(Belgium)
	H. Sünkel	(Austria)
	C.C. Tscherning	(Denmark)
	H.G. Wenzel	(Germany)

Agenda :

1. Report of the Director of BGI
2. Report about the Executive Meeting of IAG, Columbus, Ohio, March 1992
3. IAG activities in Beijing, August 1993
4. IGC activities
5. Working Group activities
6. Subcommissions
7. Intercommission activities
8. Computation of worldwide set of 5' x 5' mean anomalies
9. Relationships with the Commission for the Geoid and the International Geoid Service
10. Directing Board membership
11. Date and place of next meeting
12. Other matters.

Participants in Board Meeting : Boedecker, Kovalevsky, Sünkel, Makinen, Tscherning, Marson, Forsberg, Balmino, G. Balma (BGI) and D. Toustou (BGI).

The chairman of the International Gravity Commission I. Marson opens the meeting with greetings and notifications from board members not able to attend.

1. G. Balmino (Director of BGI) presents overview of BGI, relationship to FAGS, IAG, IGC etc... BGI is economically supported by the french agencies CNES, INSU, CNRS, IGN, and BRGM. Currently approximately 4.5 Mo points in BGI data base ; new data base system based on ORACLE is operational, allows easy gridding + contour plots, using new SUN graphics system. Land data validation project ongoing since 3 years, marine gravity validation to be initiated.
   BGI cooperates with a group of the University of Leeds (now GETECH) about data validation, and will serve as final data depository for the gravity projects such as the South Amercian Gravity Project, the european WEEGP project, the Asian project SEAGP. In the last projects BGI is directly involved in data collection. A number of East European countries have agreed to release data for the WEEGP. Data for Albania, Hungary, Poland and Czekoslovakia have been received at BGI, data for Romania and Russia are expected later. Data for Germany represents a problem. A similar project in South-East Asia have also yielded new data releases, data for Mongolia are e.g. now in Leeds, soon to be delivered to BGI. Some countries such as China and India have so far not been willing to release data to the projects or BGI.
   BGI plans to initiate limited collection of digital terrain model (DTM) data, first concentrating on the Mediterranean area, and in close collaboration with the group of F. Sanso in Milano.
   Discussion of future data exchange media : CD-ROM or ftp links ? Both are planned, ftp tests to start in January, CD-ROM investigations to begin in 1993.

I. Marson reads a fax from Medvedev urging cooperation with BGI, would like details about data requests for Russia. Dir. Board wants to inquire about data formats and exchange policy.

2. President of BGI Board now member of IAG Board. IGC Board established, E. Klingele nominated as 2nd secretary. WG's are now officially recognized as WG's of IGC rather than BGI. Too few names of national representatives were available at time of press for the Geodesist's Handbook. Marson to write to all countries requesting names.

3. IAG programme in Beijing includes a session on precise gravimetry, which should be of direct relevance to BGI. No special IGC meeting will be organized.

4. Fundamental stations in Russia now open to foreigners, Russia looking for international cooperation in absolute gravimetry. DMA interested in supporting absolute gravity project in Eastern Europe, DMA requests IGC to be official organizer, e.g. for a 2-month campaign. 1994 looks an appropriate period, Marson to contact DMA. It is proposed to expand IAGBN to more stations, including more Laser/VLBI/GPS fiducial points. Boedecker stresses the need for better global distribution of the absolute stations.

9. (moved earlier). Hans Sünkel informs on International Geoid Commission activities. Working arm of the Geoid Commission (the International Geoid Service) established at Politecnico di Milano, operational since Sept. 1. Course on global geoid determination planned for spring 1993. Sünkel proposes a joint meeting of the Geoid and Gravity Commissions to be held in Graz in September 1994. This was approved by the BGI Board.

5. With Ken McConnell retired, WG1 (Data Processing) needs a new chairman. WG1 has had a successful workshop on data validation, and a preparation of a world gravity map in Canada on behalf of BGI. The decision of the future of the group to be postponed until after the upcoming marine gravity validation workshop. WG2 (Absolute Gravimetry) have continued the collection of absolute gravity stations in the IAGBN-A and -B station series. Measurement of remaining "A"-stations in Africa, India, Saudi-Arabia and Siberia, is a problem. Discussion of whether "B" stationsz should be all absolute stations available, or just a geographically balanced subset, not yet decided. For WG5 field programs are ongoing with simultaneous measurements by absolute and superconducting instruments. For WG6 (Intercomparison of absolute instruments) a continuing field campaign is planned at Sevres.

6. Marson suggests that inactive subcommissions be discontinued, but some action is proposed to revitalize the missing ones, e.g. the African Subcommission. Marson to write letters.

7. Relationship to geoid service already presented. It is proposed to make more contacts towards geophysical organizations.

8. Prediction software developed by Wenzel's working group. Project have been discontinued by BGI, Balmino proposes to wait for a time to allow data sets from the ongoing validation/collection projects to be completed.

10. Gerd Boedecker and Rene Forsberg voting members of BGI Board (forgotten in Geodesist's Handbook). Ken McConnell to be replaced by Toni Lambert, as chairman of WG1. Nomination accepted, but final approval to be given by the IGC assembly in Graz, 1994.

11. Next meeting of the BGI Board and IGC to take place in Graz, September 1994.

12. Announcement of meeting on Marine Gravimetry in St. Petersburg, Russia, December 1992. Marson will represent BGI at the meeting.

The chairman of the IGC thanks the participants for coming to Toulouse and G. Balmino for arranging the meeting.

RF 9 NOV 1992

PART III

WORKSHOP ON MARINE GRAVITY DATA VALIDATION

Toulouse Oct. 27-28, 1992

BGI WORKSHOP
VALIDATION OF MARINE GRAVITY DATA
Toulouse (France), Oct. 27-28, 1992

Introduction

After all land data had been validated on a one by one source basis using the validation tools developed in house (SYSTEVAL, VERSET/DIVA), plans were made in 1990, within the activities of WG1 and with the help of some of its members, to develop similar software for the validation of marine data, especially to solve for cross-over minimization parameters. A program (SEAGRA) for performing part of this task, was received from H.G. Wenzel. It was installed, upgraded. Then, the decomposition of each cruise into legs was analyzed and implemented in an automatic mode in late 1991. Also, consideration was given to proper editing and to the determination of drifts within a cruise.

It was then necessary to test the whole approach against the experience of other groups engaged in this activity and this leads to the organization of the Toulouse Workshop in the BGI premisces.

Because of the character of the workshop topics, the attendance was not so large (see list), but it was very fruitful. The basis was that each participating group had first to present his own methodology and software. Then there were reports on a test case distributed to some volunteering participants a few months before the meeting. Quite interesting discussions took place on the comparisons of approaches, algorithms, and results. And finally, three groups had the opportunity to demonstrate their software capabilities on the BGI workstations and on PC's, and incredibly no visitor's effort (or almost none) manifested on that occasion !

List of Participants

A. Adjaout	Bureau Gravimétrique International, Toulouse, France
G. Balma	Bureau Gravimétrique International, Toulouse, France
G. Balmino	Bureau Gravimétrique International, Toulouse, France
R. Forsberg	KMS, Geodetic Division, Copenhagen, Denmark
J. Halpenny	Geological Survey of Canada, Ottawa, Canada
J.M. Lemoine	Dept. de Géodésie Terrestre & Planétaire, GRGS, Toulouse, France
M.F. Lequentrec-Lalancette	EPSHOM, Brest, France
D. Manton	GETECH/ULIS, Leeds, United Kingdom
I. Marson	Dept. of Naval Architecture, Marine & Environmental Engineering, Trieste, Italy
M. Sarrailh	Bureau Gravimétrique International, Toulouse, France
D. Toustou	Bureau Gravimétrique International, Toulouse, France
H.G. Wenzel	Geodätisches Institut, Univ. Karlsruhe, Karlsruhe, Germany

BGI WORKSHOP
VALIDATION OF MARINE GRAVITY DATA
Toulouse (France), Oct. 27-28, 1992

Tuesday, Oct. 27

a.m.	9.30- 9.45	Welcome and Introduction	G. Balmino (BGI)
	9.45-10.15	Data Archival at B.G.I.	D. Toustou (BGI)
	10.15-10.45	Data Processing at SHOM	M.F. Lequentrec (SHOM)
	10.45-11.00	Coffee Break	
	11.00-11.30	Air Borne Gravity over Greenland	R. Forsberg (KMS)
	11.30-12.00	Report 1 on test case	H.G. Wenzel (Univ. Karlsruhe)
	12.00-12.30	Report 2 on test case	J. Halpenny (G.S.C.)
	Lunch at FIAS		
p.m.	14.00-14.45	Report 3 on test case	D.C. Manton (GETECH)
	14.45-15.30	Validation Methods at BGI	A. Adjaout, M. Sarrailh (BGI)
	15.30-16.15	Report 4 on test case	A. Adjaout (BGI)
	16.15-16.30	Break	
	16.30-17.30	Discussion (beginning) Proposed topics : - data archival - cross-over : determination, archival/reprocessing - use of satellite altimetry - miscellaneous	led by G. Balmino (BGI)
	Workshop dinner		

Wednesday, Oct. 28

a.m.	9.30-11.00	Demonstration of software capabilities : . BGI . GSC . GETECH	
	11.10-11.15	Coffee Break	
	11.15-12.15	Discussion (cont.)	
	12.15-12.30	Recommendations	
	12.30	End of workshop	

THE GRAVITY DATA BASE OF BGI

Denis Toustou
Bureau Gravimétrique International
Institut Géographique National
Toulouse, France

1. CONCEPT OF A DATA BASE

Computerizing all activities (management, research, production) within a given organization has lead in the recent years to a large increase of data stored on magnetic tapes over disks... However, very soon appeared the problem of using and updating these data, on one hand for they usually arrive in a non homogeneous form, on the other hand because no global data management system exists to manipulate them. From this the concept of data base appears, which may be defined as a data set managed by a Data Base Management System (cf. Fr. Duquenne).

1.1. Traditional Approach by Files

It may be depicted by the scheme of figure 1

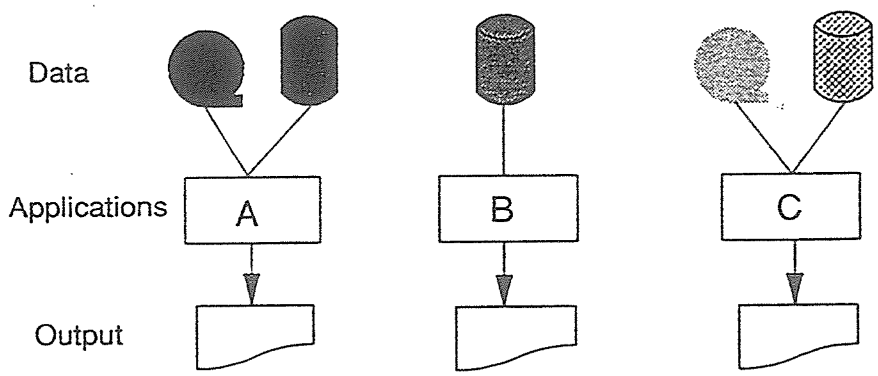

Fig. 1. Managing data with files

The disadvantages of this configuration are :
- the increase of managed and stored volumes,
- the redundancy,
- the risks of incoherence
- the dependence between datafiles and programs.

1.2. Approach by Data Base

The concept is illustrated on figure 2

DATABASE = DATA + RDBMS

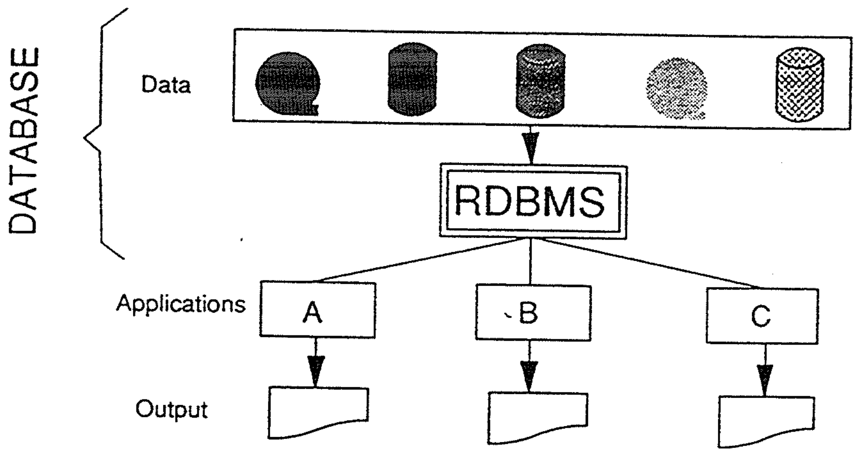

Fig. 2. The data base approach

The advantages are essentially the following :
- data organised and managed to satisfy all the applications,
- data are available for several users at the same time
- integrity and coherence of data are guarantied.
- no maintenance.

1.3. Relational Model

They are three main types of data base : hierarchical, in network and relational.

Over the past several years, Relational Data Base Management Systems (RDBMS) have become the most widely accepted to manage data.

A RDBMS is a software able to describe, store, retrieve, update, modify, insert, delete data sets and which guarantees the security, the confidentiality and the shared availability.

For the user, the physical storage is transparent : he knows only the logical configuration of the data.

Role of DBA : Data Base Administrator

In general, every data base requires at least one person to perform DBA duties. The DBA plays a very important role and as the primary "manager" of a data base system, he is responsible for seeing that the software and hardware forming the data base system meet the needs of the users. Thus, the DBA's concerns may include :

- software installation and maintenance
- data base tuning for optimal data base use
- data base design
- data base accuracy
- data base security
- data storage
- data availability
- data recovery.

2. BGI DATA BASE

The gravity data base of BGI is now installed on an IBM 9121 computer (power : 23 Mips) of the CNES (Centre National d'Etudes Spatiales) computer center.

It is managed using the Oracle Data Base Management System Version 6 with the option TPO : Transaction Processing Option, which is in fact an accelerator.

2.1. Logical Data Design

The major functions and entities are shown on figure 3.

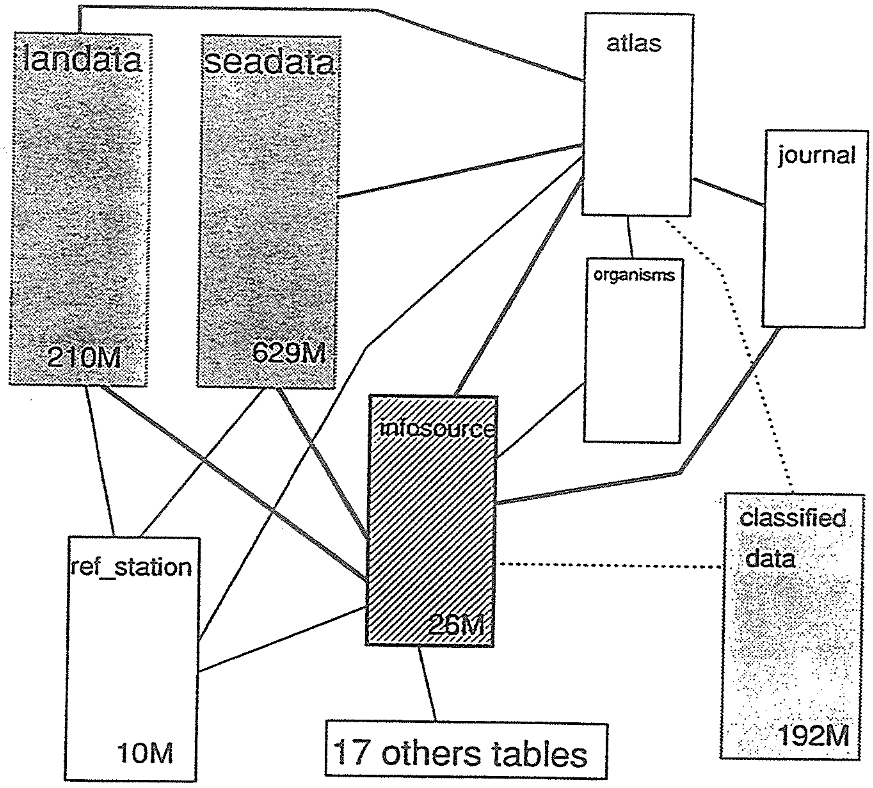

Fig.3. The BGI data base overall design

2.2. Tables

Data are organised in tables (user's basic logical unit), stored in tablespaces (Oracle logical unit) which are associated with physical files (unknown by the users). A table is a basic unit of data storage and is defined with a table name and a set of columns (up to 254 columns are allowed). Each column is given a column name, a data type and a width. For each column is possible to specify wether it requires values or wether it allows null values (null ≡ no data ≠ zero), to specify default values and referential constraints. A record is a row of the table and a column is equivalent to a field.

Two main tables Landata and Seadata contain all the discrete open file measurements on land and at sea with all the associated fields (annexes 1 & 2), especially the observed gravity value and the gravity correction. The Landata table needs 210 Megabytes of storage and the Seadata table about 629 Megabytes.

The Infosource table contains for each sources, all the information necessary for the management of the data survey (annex 3) and is the central axis of the relational scheme, with many "pointers" such as country code, owner, confidentiality, warning,...

The Atlas table (annex 4) contains all BGI country code with associated name, DMA code, IGN code, ULIS code and surface.

The Journal table ensures the progress report of the new data integration.

The Ref station table contains all the reference stations with associated parameters.

2.3. Indexes

To improve the performances of the data base, it is essential to use indexes. They are optional structures (in B-tree form), associated with a table which is used by the RDBMS to locate rows of that table quickly.

Indexes can be calculate for one column (simple index) or several (concatenated index) and can be used to guarantee that every row is unique (unique index).

On Landata and Seadata tables we use three indexes : one on the country code, one on the source number, and another concatenated on longitude and latitude.

2.4. Views

To control the access to the data we use views which are data base objects that can often be treated just like a table. It is a logical representation of a table or a combination of tables. Views provide a means to present a different representation (such as subsets or supersets) of the data and allow to taylor the representation to different types of users (example : to provide an additional level of table security by restricting access to a predetermined set of row and/or columns of a table). Because views occupy no storage space, they are called "virtual tables".

2.5. SQL Language

At the heart of the Oracle RDBMS is the SQL data language developed and defined by IBM Research. It has been redefined by the American National Standards Institute (ANSI) as the standard language for relational data base management system.

SQL statements are often divided into two categories :
- Queries and data manipulation statements
- Data definition statements and Data Control statements.

Example of query :

```
SELECT lati, longi, alti, Gvalue FROM landata
    WHERE pays IN (select numpays from atlas where nompays =
'CZECHOSLOVAKIA') AND alti ≥ 1500 GROUP BY isource ORDER BY lati DESC ;
```

This statement selects the latitude, longitude, elevation and observed gravity value for land measurements in Czechoslovakia which elevation is greater than equal to 1500 meters. The extracted records are grouped by survey and sorted by latitude values in descending order

2.6. Tools

We use several others tools to manage the data base :

- SQL DBA : used by DBA to manage the data base
- SQL forms : convivial interface to manipulate the data
- Pro*Fortran precompiler to insert SQL statements in Fortran code
- SQL loader to load external data in Oracle tables.

3. CHARACTERISTICS AND PERFORMANCES OF THIS CONFIGURATION

Because of the size of the data base, the implementation of the system has been preceded by a study phase for performances.

3.1. Physical Consequences

To manage the BGI open file measurements (1,8 M land data - format : 126 characters & 2,6 M sea data, format : 145 characters) plus classified data sets and the indexes, we are using 2.2 Gigabytes : 1,6 Go for tables and 0.6 Go for indexes.

The obtained mean access time are :

- extraction of 1000 points according to the country code (simple index) : 1,5 s.

- extraction of 1000 points according to a geographic criterion (concatenated index) : 6,5 s.

- insertion of 1000 points : 3,5 s.

These results, quite satisfying for this kind of applications, are due to essentially :

- the choice of appropriate tools :
  It appeared that fastest accesses as well for updating than for consulting are obtained with Pro*Fortran (a Fortran program including SLQ orders), using cursors. Even for data loading from sequential files, Pro*Fortran is more efficient than SQL-loader. All the routine operations (updating, extractions) are written in Pro*Fortran, whatever execution mode : batch or via form.

- the choice of index :
  Index are essential, despite the important increase of disk space (+ 50 %). A judicious choice is essential to improve the performances, some examples are revealing :

Extraction of 10000 points BGI data	Without index	With index	Concatened index	2 different indexes
By country	112 s	14 s		
By source	52 s	7 s		
By geographic area longitude + latitude			55 s	67 s

- the control of the tables splitting : the big tables of the application must not be splitted in any case (i.e. stocked in different separated physical areas). The volume of this tables must be carefully evaluated. They are created using the parameter "initextent" (size of the 1rst stocking area), in order to control the stocking of these tables.

- the organization of the tables in the tablespaces :
  . the allocation of the tablespaces and their sharing on the disks have been done in order to favour the most frequent accesses.
  . the temporary tables used for sorting are isolated in a particular tablespace. These very unstable tables, their size is not controlled by the users, and often very big ones can disorganize the physical space. It is better to isolate them.

3.2. Logical Consequences

They are essentially due to the benefits offered by a RDBMS :
- hardware independence : Oracle is available on any system : UNIX, CDC, IBM, PC,...
- no maintenance : RDBMS manages the Archiving Process
- no archive files any more because all the data fields are stored in tables, they are on line.
- open structure : the flexibility on data modeling permits to modify the logical scheme of the data.
- independence of physical storage and logical data design.
- improved security : the user's privileges are controlled by the DBA, the use of views provides an additional level of table security (restricting access) and the Rollback process restores the data base, undoing all the changes done in the current transaction.
- a high-level data manipulation language SQL.
- comfort because the access to all data is very easy.

4. NEW DATA FORMATS (see annexes 5 & 6)

Two new formats are used to manipulate the data out of the Oracle System. They include the observed gravity value and the correction of observed gravity.

EOL : External Oracle Land data format - 126 char.
EOS : External Oracle Sea data format - 145 char.

5. DATA VALIDATION

Three main software are used at BGI to validate data.

Systeval : Systematic Validation of Land data

Running in batch mode, it detects by collocation the "gross errors" before the interactive step.

Diva/Verset : Graphic Interactive Validation after Collocation

With multiple point management, coloured histogram and shaded coverage display, searching correlations between gravity anomalies and geographical parameters, and interactive mapping of anomalies as a visual control.

Diva represents 10 000 lines of Fortran, using the graphic library IGL/PLOT 10 of Tektronix. It runs on CYBER 2000 (CDC) with NOSVE as operating system (cf. Bulletin d'Information n° 67, December 1990).
Today it is redesigned for migration on UNIX platform (workstation), using PHIGS as graphic library.

Seaval

The new validation software for marine data is in course of development at BGI, based on collocation and least squares adjustment method.

Reference

Duquenne, Fr., Base de données géodésiques, Tunis, 1990.

ANNEX 1

Description of LANDATA

Name	Null?	Type	Comments	assoc. table
ISOURCE	NOT NULL	CHAR(8)	SOURCE number	infosource
LATI	NOT NULL	NUMBER(8)	LATITUDE	
LONGI	NOT NULL	NUMBER(9)	LONGITUDE	
POSIAC		NUMBER(2)	accuracy of position	posi_accur
OBSERTYP	NOT NULL	NUMBER(1)	type of observation	t_obser_typ
ALTITYP	NOT NULL	NUMBER(2)	elevation type	t_alty_typ
ALTI		NUMBER(8)	ELEVATION	
ALTIAC		NUMBER(2)	accuracy of elevation	alti_accur
ALTIDET		NUMBER(2)	determinat. of elev.	t_alti_det
GVALUE		NUMBER(9)	OBSERVED GRAVITY	
GACCU		NUMBER(2)	accuracy of gravity	g_accur
GCOR		NUMBER(6)	correction obs. gravi.	
FREEAIR		NUMBER(6)	FREE AIR anomaly	
BOUGUER		NUMBER(6)	BOUGUER anomaly	
FREEAST		NUMBER(3)	free air stand. devia.	
BOUGST		NUMBER(3)	bouguer stand. devia.	
TERCORINF		NUMBER(2)	informat. terrain corr.	tercor_inf
DENSITY		NUMBER(4)	used density	
TERCOR		NUMBER(6)	terrain correction	
APPARAT		NUMBER(3)	used apparatus	t_apparat
NBORIGI		CHAR(7)	original numbering	
PAYS	NOT NULL	CHAR(3)	country code (bgi)	atlas
NBSEQ	NOT NULL	NUMBER(6)	sequence number	
CONFID		NUMBER(1)	confidentiality	confiden
VALID	NOT NULL	NUMBER(1)	VALIDITY	validity
POSISYS		NUMBER(2)	system of position	t_posi_sys
ALTISUP		NUMBER(8)	supplemental elevation	
REFSTA		CHAR(6)	reference station	ref_station

ANNEX 2

Description of SEADATA

Name	Null?	Type	Comments	assoc. table
ISOURCE	NOT NULL	CHAR(8)	SOURCE number	infosource
LATI	NOT NULL	NUMBER(8)	LATITUDE	
LONGI	NOT NULL	NUMBER(9)	LONGITUDE	
POSIAC		NUMBER(2)	accuracy of position	posi_accur
OBSERTYP	NOT NULL	NUMBER(1)	type of observation	s_obser_typ
ALTITYP	NOT NULL	NUMBER(2)	elevation type	s_alty_typ
ALTI		NUMBER(8)	ELEVATION	
ALTIAC		NUMBER(2)	accuracy of elevation	alti_accur
ALTIDET		NUMBER(2)	determinat. of elev.	s_alti_det
MATHZON		NUMBER(2)	Matew's zone	
ALTISUP		NUMBER(8)	supplemental elevation	
GVALUE		NUMBER(9)	OBSERVED GRAVITY	
GACCU		NUMBER(2)	accuracy of gravity	g_accur
GCOR		NUMBER(6)	correction obs. gravi.	
FREEAIR		NUMBER(6)	FREE AIR anomaly	
BOUGUER		NUMBER(6)	BOUGUER anomaly	
FREEAST		NUMBER(3)	free air stand. devia.	
BOUGST		NUMBER(3)	bouguer stand. devia.	
TERCORINF		NUMBER(2)	informat. terrain corr.	tercor_inf
DENSITY		NUMBER(4)	used density	
TERCOR		NUMBER(6)	terrain correction	
VELOCI		NUMBER(3)	velocity of the ship	
JDATE		NUMBER(9)	date in julian day	
NBORIGI		CHAR(7)	original numbering	
PAYS	NOT NULL	CHAR(3)	country code (bgi)	atlas
NBSEQ	NOT NULL	NUMBER(6)	sequence number	
CONFID		NUMBER(1)	confidentiality	confiden
VALID	NOT NULL	NUMBER(1)	VALIDITY	validity
POSISYS		NUMBER(2)	system of position	s_posi_sys
REFSTA		CHAR(6)	reference station	ref_station
EOTVOS		NUMBER(5)	Eotvos correction	
NBLEG		NUMBER(3)	leg number	

ANNEX 3

Description of INFOSOURCE

Name	Null?	Type	Comments	assoc. table
ISOURCE	NOT NULL	CHAR(8)	source number	
INITDAT		DATE	date of data receipt	
CORDAT		DATE	date of the last correc	
CONFID		NUMBER(1)	confidentiality	confiden
CONFINF		CHAR(255)	information about confi.	
NBPOINT	NOT NULL	NUMBER(6)	number of points	
LONGMIN	NOT NULL	NUMBER(8)	minimal longitude	
LONGMAX	NOT NULL	NUMBER(8)	maximal longitude	
LATMIN	NOT NULL	NUMBER(8)	minimal latitude	
LATMAX	NOT NULL	NUMBER(8)	maximal latitude	
PAYS	NOT NULL	CHAR(3)	country codeatlas	
LISTEREF		CHAR(255)	liste of ref. station	ref-station
GCALCUL		CHAR(255)	infor. about G computat.	
GINFO		NUMBER(1)	!	
APPARAT		NUMBER(3)	!for marine data	s-apparat
APPARACON		NUMBER(2)	!	appara_condi
OWNER		CHAR(90)	owner of the data	organisms
INTITULE		CHAR(210)	title of the survey	
PUBLICATION		CHAR(100)	publication	
AUTEURS		CHAR(80)	authors	
COMPILDAT		DATE	date of compilation	
WARNING		CHAR(255)	warning	
REMARQUE		LONG	remarks	
ORISNB		CHAR(5)	origi. numb.of the source	
LONGITYP	NOT NULL	NUMBER(1)	type of longitude	longi_typ

ANNEX 4

Description of the JOURNAL

Name	Null?	Type	Comments	assoc. table
ISOURCE	NOT NULL	CHAR(8)	source number	infosource
INITPOINT		NUMBER(6)	initial numb. of pts	
FINAPOINT		NUMBER(6)	final number of points	
FILENAME		CHAR(20)	filename for transfert	
STATE	NOT NULL	NUMBER(1)	state of validat.,insert.	state_typ

Description of the ATLAS

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NAMEPAYS	NOT NULL	CHAR(80)	country name	
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ULISCODE		CHAR(3)	ULIS country code	
SURFACE		NUMBER(8)		

Acquisition and Validation of Marine Gravity Data at S.H.O.M (Service Hydrographique de la Marine)

by M.F. Le Quentrec-Lalancette
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As presented at the workshop on Marine Gravity Data Validation, Toulouse October 27_28, 1992

Abstract:

The acquisition of marine gravity data on the hydrographic vessels, is described. The accuracy of the data is estimated at each step of the processing tools. Examples are picked from different survey and calibration procedures made by the SHOM.

I. – Introduction

All the naval and oceanographic equipments of the S.H.O.M. are dispatching between hydrographic survey units. These are three, the Atlantic Hydrographic Survey Unit (MHA), the Mediterranean Oceanographic Unit (MOM) and the Pacific Oceanographic Unit (MOP Tahiti/Noumea) (Figure 1) . These missions can count on hydrographic and oceanographic vessels from which the D'Entrecastaux and the Esperance based in Toulon and Brest are equiped with a gravimeter from the Bodenseewerk Company. On the D'Entrecastaux, until 1991 there was a KSS5 gravimeter and now it has been replaced by a new generation of spring gravimeter the KSS31. The Esperance is equiped by a KSS30. By the way, Each oceanographic vessel is equiped with a land gravimeter (Worden) to tie the survey with base stations and then international gravity network.

The gravimetric surveys are done together with hydrographic one in the study areas. In each survey, precise instructions are written to point out the way of acquisition of geophysical parameters (spacing of the tracks, of the cross tracks, of measurements..). The prospection areas are placed in oceanic great depth oceans in the N.E. Atlantic ocean and the Mediterranean Sea. Right now, we receive at Brest (EPSHOM) an average of fifteen to twenty thousand measurements yearly, equivalent to an average of four hundred fifty kilometers of tracking. So, we need some archival structures and data processing that we are actually developping in Brest. This presentation will focus on the description of the acquisition of data at sea and the validation before integration in a data base. Examples are taken from the surveys made with the KSS5 and KSS30 gravimeters.

II. – Equipments on board

The instrumentation and equipments on board are almost the same for the two vessels. The figure 2 describes the installation frame on the Esperance (KSS30 gravimeter). The sea gravimeter is composed by :

- The gravity sensor,
- a platform gyro-stabilized,
- a central unit with electronics for gravimeter and gyro integrated processor and data output (analog registration and magnetic tape).

The navigation data , allows the KSS30 unit to correct in real time the acceleration of the ship (pitching and rolling). Test made at the installation of the gravimeters have shown that these are good corrected except during rapid courses variation (ref a). The KSS5 and KSS30 gravimeter sensor have been tested with respect to the sea state. As we can supposed, the KSS5 shows a bad way of running when the sea becomes rough to very rough (figure 3).

III.- The prospection survey

The sea gravimeter makes relative measurements. A typical survey is then divided in two parts, first of all the connection to base stations and then the prospection survey at sea.

A – Tie to Base station (figure 4 et 5)

Connection to base station where gravity in an international gravity network is known allows the absolute locking of the sensor. Periodic harbour measurements during the survey allows the calculation of the instrumental drift due to time dependant damages of the electronic parts.

Most of the harbours have a reference gravity station which is tied to a network as IGSN71 or Postdam. Right now only the IGSN71 is available in the Hydrographic and Oceanographic survey units. But in some cases, we can do some mistakes between base stations due to the lack of accuracy of these references (ref b).
To tie the onboard gravimeter measurements a land gravimeter is used. The connection is made by classical relations which takes into account the elevation of the quay with respect to tide variations of sea level.
On board during the whole time of the call at the harbour, the gravimeter is running together with the echo sounder. Then the gravity measurements can be reduce to mean sea level . The figures 4 and 5 resume the corrections.

Index of Gravity station (figure 4) :

For each gravity reference measurements on land, all the informations are put on file in the EPSHOM and sent to B.G.I. Right now, for 1965 an average of 55 stations have been recorded in the harbours of the study areas. The point of reference at quay is used in cases of lack of land gravimeter.
The accuracy is dependant on the accuracy of the reference base station measurements. (In Antilles an error of almost 1 mgal appeared due to the lack of acurracy of base station tied to the IGSN71, ref b) and a).
The lack of land gravimeter can be prejudicial and induces errors on the locking.

B – Measurements along the tracks

The central acquisition unit named Hydroboucle allows the synchronisation of the whole parameters recorded on board. The KSS 30 Gravimeter unit is connecting to the Hydroboucle network by a serial interface.

Processing tools

Each second, the navigation data are sending to the gravimeter and consisting of the latitude, longitude, heading (gyro–compass) and speed (Loch electromagnetic). These datas allows the gravimeter to compensate and adjust the pitching an rolling of the boat.

Each 6 seconds, the KSS 30 send a message composed by the date, the clock time, the measurements, the real time eotvöss corrections, free air anomaly and Bouguer anomaly. Alone the date, time and measurements are recorded. These values are resulting of a low pass filtering which induces a phase difference. The filter used in the Esperance, for example, induces a time delay around three minutes.
The localisation and gravity measurements are mixing after a replay of navigation data recorded each 2 minutes. These data are oversampling at 1 minute then filtering (the same filter as for the gravity one is applied) and the eotvöss correction can be computed.
Then the free air anomaly and the absolute gravity are computing after drift correction and introduction of reference measurements.

The Eotvöss Correction

The real time eotvöss correction computed by the KSS 30 unit is not recorded because the navigation data sent, each 1 minute, to the gravimeter are not free of erromeous data (figure 7).
When Gravity and Navigation data are homogenizing, the eotvöss correction is done with the classical formulas :

$$C = 0.004\ v^2 + 7.5029\ v \cos L \sin C\ \text{(mgal)}$$

v : speed over the ground
C : heading over the ground
L : latitude

These correction greatly depends on the position and then on the navigation system used during the survey. The position must be computed with a good precision. An accuracy of 0,1 mgal is realized when the speed of the ship is known to 0.1 knots.
More over, the errors will be minimized if the choice of the courses during the survey are well done.
This choice is the result of a compromise between the hydrographic needs, the sea state, the minimization of the accelerations.
In 1991, the accuracy of this correction has been estimated with respect to navigation systems (figure 7), for the KSS 30 gravimeter. Note that the sampling of navigation in this example does not allow to compute the eotvöss correction in some cases, like turn or decrease in speed due to specific measurements (celerity measurements to reduce echo sounder data for example). In these cases, the parts of the tracks are eliminating.

IV. – Survey validation

The combination of all the causes of errors at each step of the acquisition may induce an accuracy of the survey showed in figure 8. In practical use, a post validation is made at the end of the survey.
The analyse of the tracks with respect of the heading, the direction of the swell is done to check possible bad corrected accelerations inducing oscillations in the gravity signal. According to the type of errors, data are filtered or classified as uncertain or eliminated. The estimation of the accuracy of the whole survey is done by the analyse of the crossing tracks. The cross-over discrepancies computed allow to give a code of quality of the survey.

V. – Conclusion

These description of an acquisition of marine gravity data points out the fact that the final accuracy depends on the checking made at each processing step including the external conditions as the sea state or the direction of the swell. In most of the surveys, the crossing tracks give good informations to qualify the whole gravity acquisition.

VI. – REFERENCES

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Annales Hydrographiques, 5ème série, V 4, F 1, N 743, pp 85–180.

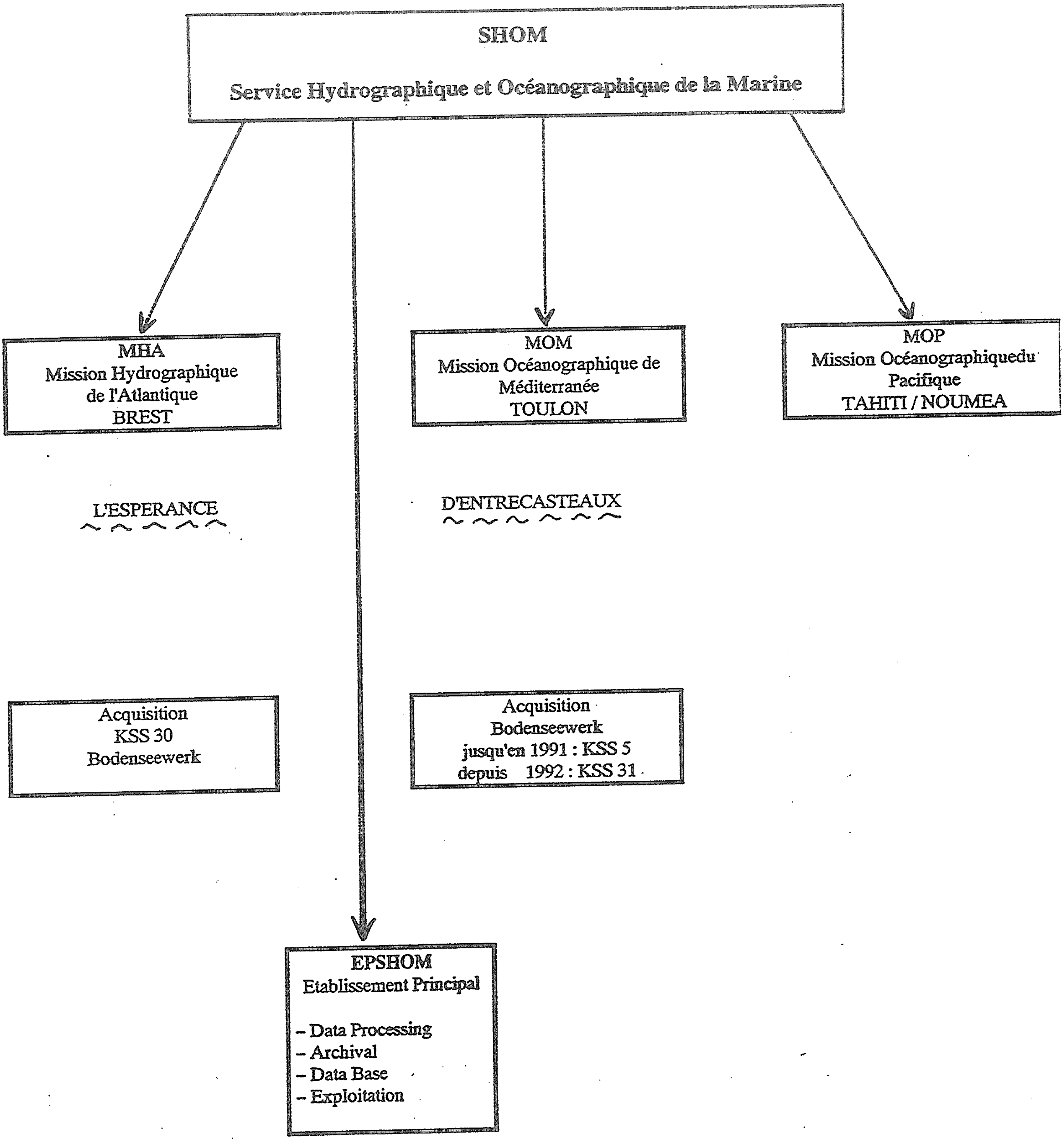
Référence b

Le Visage Ch., 1987.
Rapport Particulier n° 32 MOM/NP du 25 janvier 1989.

Référence c

Boulard M.M., 1991 : Mission Océanographique de l'Atlantique.
Annales Hydrographiques, 5ème série, V 17, N 764, pp 57–114.

Figure 1


SHOM
Service Hydrographique et Océanographique de la Marine
MHA
Mission Hydrographique
de l'Atlantique
BREST
MOM
Mission Océanographique de
Méditerranée
TOULON
MOP
Mission Océanographiquedu
Pacifique
TAHITI / NOUMEA
L'ESPERANCE
D'ENTRECASTEAUX
Acquisition
KSS 30
Bodenseewerk
Acquisition
Bodenseewerk
jusqu'en 1991 : KSS 5
depuis 1992 : KSS 31
EPSHOM
Etablissement Principal
– Data Processing
– Archival
– Data Base
– Exploitation

SEA GRAVIMETER ON BOARD

KSS 30

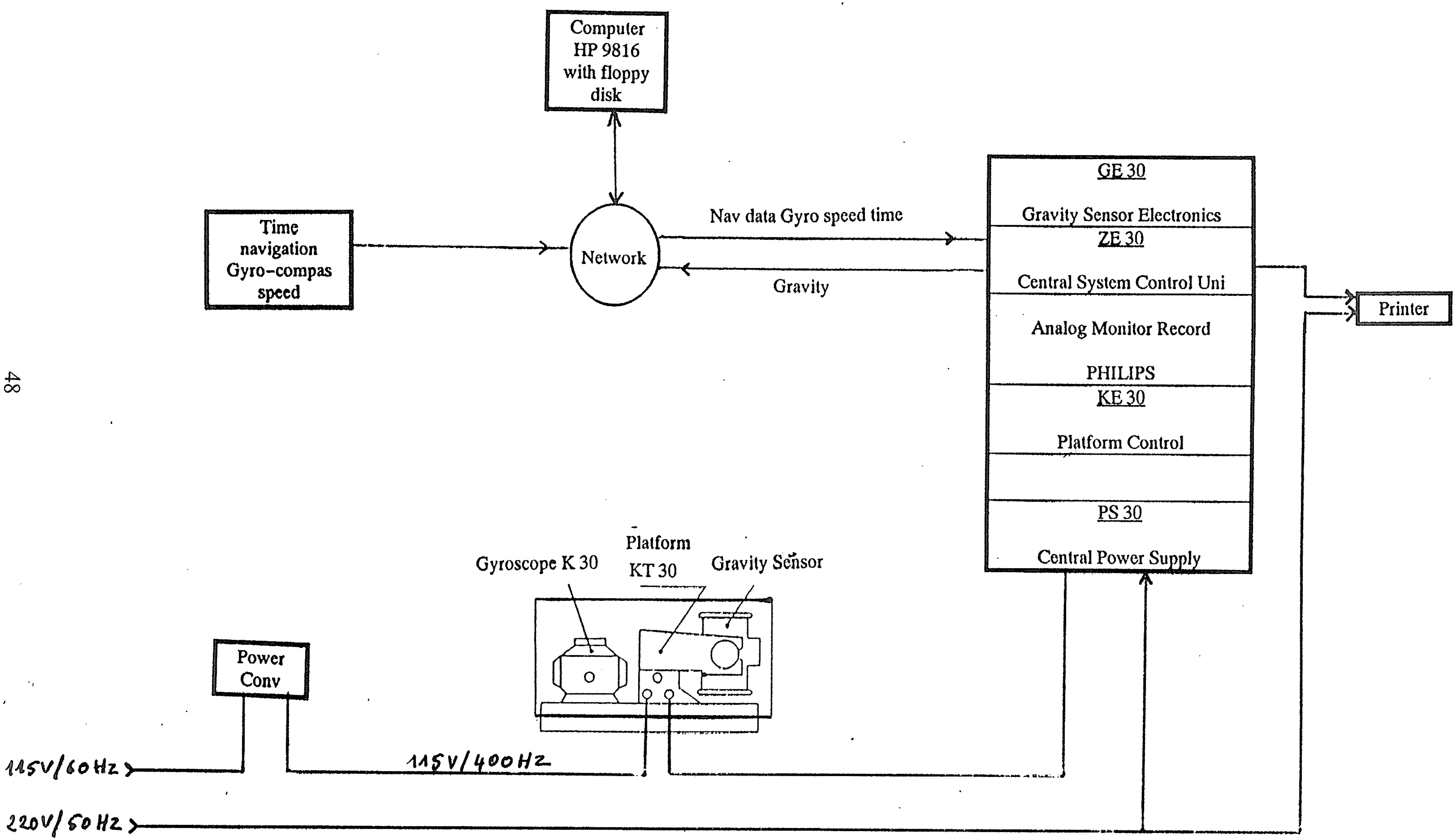


Figure 2

Figure 3

ACCURACY OF GRAVITY SENSOR

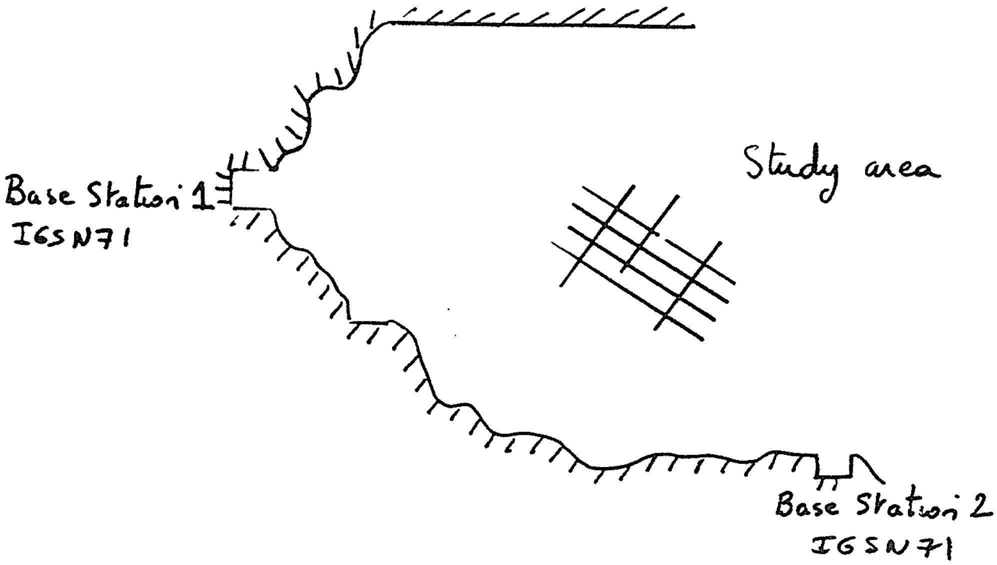
KSS 5 : Horizontal lever spring balance system

sea state	accuracy
calm sea	1 mgal
rough sea	3 mgal
very rough sea	inaccurate

KSS 30 : Vertical measurement systems

sea state	accuracy
calm sea	0.5 mgal
rough sea	1 mgal
very rough sea	3 mgal

Figure 4



FICHE DE STATION GRAVIMETRIQUE

DIFFUSION

DESCRIPTION

NOM DU POINT : SAO MIGUEL - PONTA DELGADA - MOLE SALAZAR

PAYS : PORTUGAL - ACORES .... MISSION : M.O.M .... DATE : 07 avril 1990

SYSTEME DE REFERENCE

RESEAU GRAVIMETRIQUE : I.G.S.N 71

SYSTEME GEODESIQUE : W.G.S 84 .... PROJECTION : ....

REFERENCE D'ALTITUDE : Niveau moyen .... MODELE DU POTENTIEL : G.R.S 80

DESIGNATION DES POINTS

① Bollard n° 55

Latitude : 37°44,145 N .... X : ....
Longitude : 025°39,655 W .... Y : ....
Altitude : 2,08 m ..... Hauteur au-dessus du sol : 00

○

Latitude : .... X : ....
Longitude : .... Y : ....
Altitude : .... Hauteur au-dessus du sol : ....

VALEURS DE LA PESANTEUR

①

Pesanteur absolue : g = 980 114 , 54 ..... ± .... mGal
Anomalie : à l'air libre .... = + 144,66 ...... mGal
Gravimètre : Worden n° 1246 ....

②

Pesanteur absolue : g = ... ± .... mGal
Anomalie : .... = ... mGal
Gravimètre : ....

REDUCTIONS

....

COMMENTAIRES

Point rattaché par un aller et retour aux points de référence : "Observatorio météorologico" et "Ponta do Molhe".

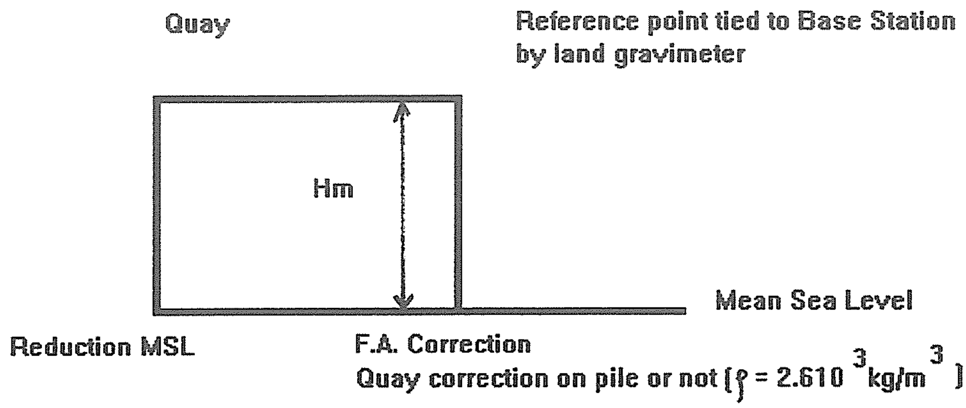
RESERVE A L'EPSHOM

N° : 54-90

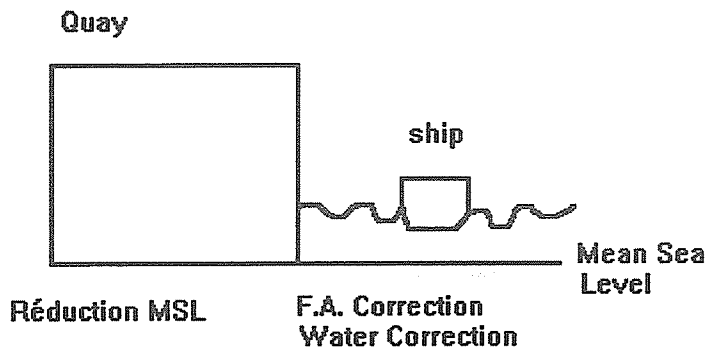
Figure 5

AT THE HARBOUR

- Connection to Base Station



- Measurements on board



If the drift is < 0.1 mgal/day $\qquad G_{MSL} = \frac{1}{n} \sum_{1} (Gi - Gc)$

the draft variation ⇒ error < 0.1 mgal

Accuracy : better than 0.5 mgal

Cause of errors :
- no land gravimeter
- Base Station (→ 1 mgal).

Figure 6

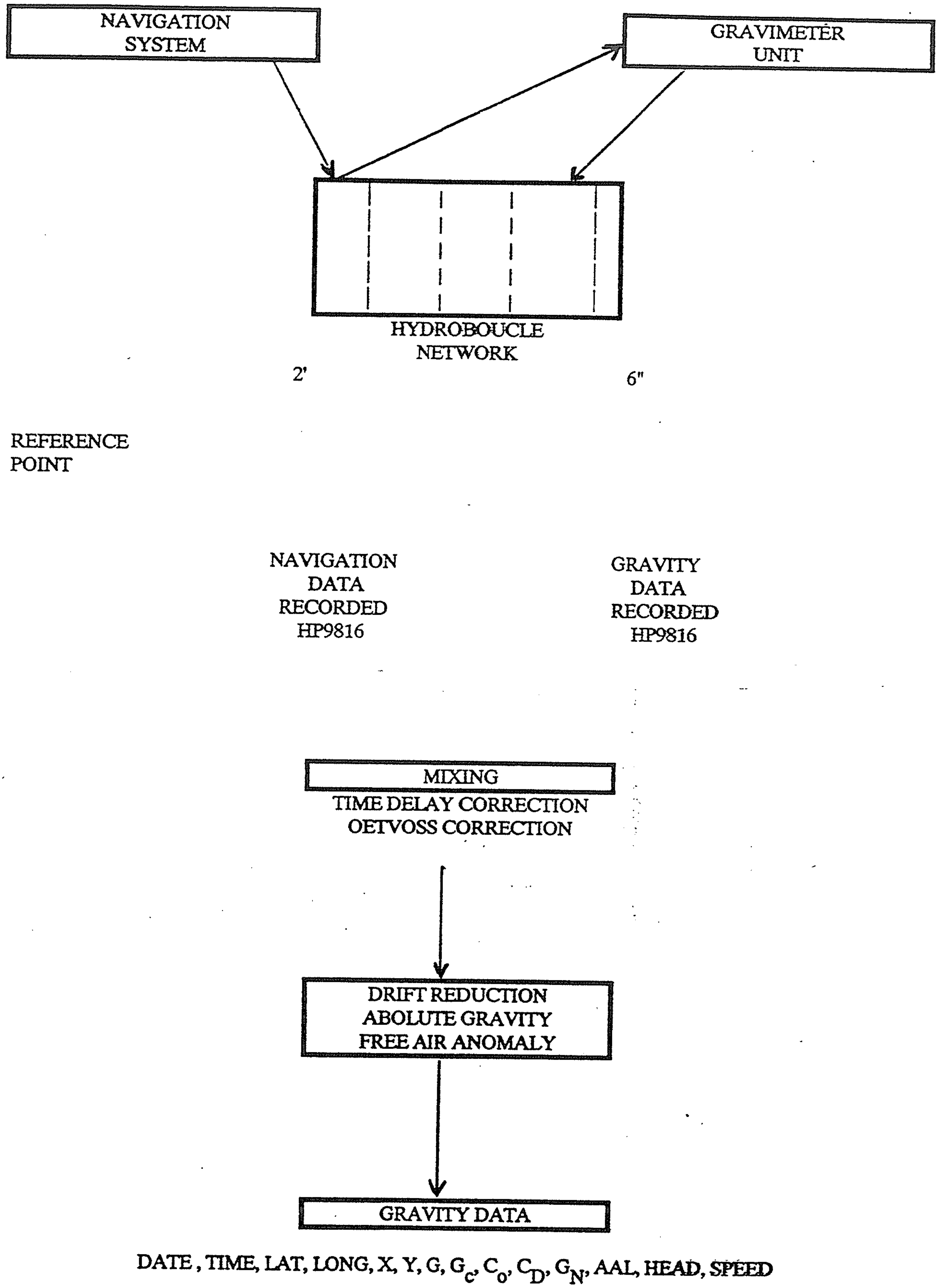
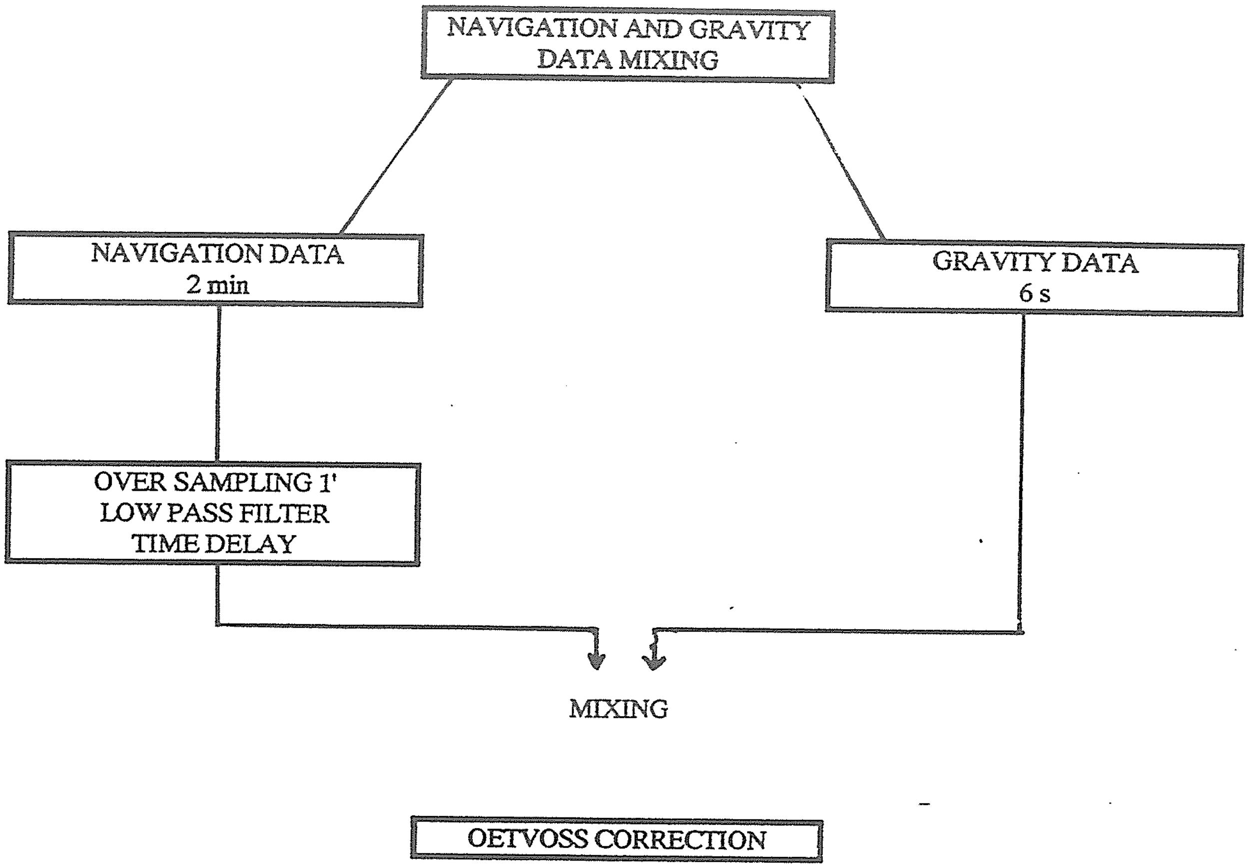

NAVIGATION SYSTEM
GRAVIMETER UNIT
HYDROBOUCLE NETWORK
2'
6"
REFERENCE POINT
NAVIGATION DATA RECORDED HP9816
GRAVITY DATA RECORDED HP9816
MIXING
TIME DELAY CORRECTION
OETVOSS CORRECTION
DRIFT REDUCTION
ABOLUTE GRAVITY
FREE AIR ANOMALY
GRAVITY DATA
DATE , TIME, LAT, LONG, X, Y, G, G_c, C_o, C_D, G_N, AAL, HEAD, SPEED

Figure 7



Accuracy :

Navigation System	accuracy
Transit, Omega (reckoning)	2 to 5 mgal
Loran C	0.5 to 1 mgal
Toran, Trident, GPSD	0.1 to 0.5 mgal

– : from Annales Hydrographiques, 17, 5, 1991

FREE AIR ANOMALY

- Drift Evaluation
  0.05 to 0.06 mgal/day

- FAA :

$$FAA = G_{ref} + \Delta g - G_N + C_D + C_O$$

G_N : Somigliana formula (GRS 80)

Accuracy :

Sea State / *Navigation*	*Calm* *0 - 2*	*Rough* *3 - 5*	*Very rough* *6 - 7*
Transit - Omega	3 - 6 mgal	3.5 - 6.5 mgal	4.5 - 7.5 mgal
Loran C	1.5 - 2 mgal	2 - 2.5 mgal	3 - 3.5 mgal
Toran - Trident	1 - 1.5 mgal	1.5 - 2 mgal	2.5 - 3 mgal
GPSD	1 - 1.5 mgal	1.5 - 2 mgal	2.5 - 3 mgal

THE GREENLAND AIRBORNE GRAVITY PROJECT - COMPARISON OF AIRBORNE AND TERRESTRIAL GRAVITY DATA

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ABSTRACT. This paper describes preliminary results of comparisons of airborne gravity data to ground data for the Greenland Aerogeophysical Project. Upward continuation of ground truth data have been carried out by a spherical FFT approach using terrain models to avoid aliasing. Results indicate accuracies in the range of 7-16 mgal. It is believed that the majority of the error is coming from uncertain upward continuation, due to lack of gravity data and insufficient height data. The estimated error of the airborne gravity survey is 5 mgal, with a resolution around 20 km.

Introduction

A complete airborne gravity survey of Greenland has been carried out 1991-92 by the US Naval Research Laboratory and the Naval Oceanographic Office in coorperation with the National Survey and Cadastre of Denmark (KMS) and Defense Mapping Agency. This survey represents the first succesful continental-scale airborne gravity survey. The primary purpose of the survey is to provide necessary data for estimating 0.5° x 0.5° sea-level mean gravity anomalies. Additionally precise ice-cap elevation data and magnetic data have been acquired. In the project more than 250000 km of track lines were surveyed in two 2-month field seasons, using a P-3 aircraft flying at nominally 280 knots and 4100 m elevation, cf. Fig. 1.

In this paper we make a preliminary analysis of the acquired data by upward continued ground truth data. However, the lack of terrestrial gravity data and accurate digital terrain and ice thickness models for Greenland makes this comparison difficult. The location of existing gravity data in Greenland is shown in fig. 2. The results of this paper should be viewed more as a first indication of the prospects of large-scale airborne gravity surveying rather than an actual project evaluation.

The airborne gravity system

Airborne gravity surveying has been made possible by kinematic GPS, which allows vertical accelerations to be measured with sufficient accuracy to recover true gravity accelerations from the gravimeter output. In the NRL/NAVO airborne gravity survey system both a slightly modified LaCoste & Romberg model "S" gravimeter and a Bell BGM-3 or BGM-5 gravimeter have been used as gravity sensors. In this paper we have only worked with the LaCoste & Romberg data.

The GPS measurements were carried out by a set of 4 GPS receivers on the airplane, and a similar set of 4 receivers were used at the main ground reference site (Sondrestrom or Thule). In addition a number of GPS receivers were simultanously operating at a number of remote sites (cf. Fig. 1). The duplication of

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Presented at 7th Int. Symp: Geodesy. and Physcis of the Earth, Potsdam, October 1992

receivers both on the ground and in the air made it possible to eliminate a majority of the cycle slips by performing baseline solutions among the various receviers prior to the kinematic GPS solution. More details on the GPS processing may be found in Peters et al (1991).

In addition to GPS several high-resolution radar altimeters were used. The main 10 GHz NRL radar provides height measurements to an accuracy of a few cm over water or ice, and has been used for independent determination of airplane accelerations, as well as for constraining the kinematic GPS height solutions over the ocean areas, typically at the start and end of individual tracks. By combining GPS and radar profiles it has been illustrated that the ocean geoid may be recovered (Brozena et al, 1992).

Preliminary airborne gravity results

At present only the main tracks of the 1991-survey have been reduced, covering the southern half of Greenland. Only the main reference site at Sondrestrom has been used for the preliminary GPS solution, and major problems still exist in the ambiguity determinations over the extended (often 8-hr, up to more than 1000 km baseline) flights. A cross-over adjustment constraining the GPS heights to ocean radar heights using the OSU91A geoid model yields a cross-over discrepancy of 2.8 m r.m.s. This number has been verified by independent GPS measurements and GEOSAT data over the top of the ice cap.

For gravity a similar cross-over adjustment yielded 6.5 mgal, indicating the error on an individual track to be slightly less than 5 mgal. A modified reverse-time RC filter was applied to the data, yielding a zero-phase gravity filter corresponding to a resolution (width of impulse response) around 20 km, depending on actual aircraft speed.

Upward continuation of ground data

The harmonic upward continuation of the available surface gravity data is carried out using Poisson's integral, which in its spherical form reads

$$\Delta g_r = \frac{R(r^2-R^2)}{4\pi} \iint \frac{\Delta g}{s^3} \cos\phi \, d\phi \, d\lambda$$

with R the earth radius, $r = R+h$ the radius of the continuation level, and

$$s = \sqrt{r^2 + R^2 - 2Rr\cos\psi}$$

By expressing the spherical distance through the formula

$$\sin^2\frac{\psi}{2} = \sin^2\frac{\Delta\phi}{2} + \sin^2\frac{\Delta\lambda}{2}\cos\phi_1\cos\phi_2$$

it is possible to approximate the spherical upward continuation as a convolution formula in longitude and latitude, exactly evaluating Poissons integral along a chosen reference parallel $\phi = \phi_{ref}$

$$\Delta g_r = \frac{R(r^2-R^2)}{4\pi} \left[s_{ref}^{-3} * (\Delta g \cos\phi) \right]$$

This convolution may be efficiently evaluated by FFT, and by using several reference parallels in a stacking/interpolation scheme it is possible to produce fast, virtually exact upward continuation results, analogous to the multi-band spherical FFT geoid prediction technique (Forsberg and Sideris, 1992).

The advantage of the FFT method is the speed of evaluation and ease of data handling, since all of Greenland can be handled in one run. A serious drawback is the lack of realistic error estimates. Therefore least-squares collocation might be a more attractive alternative for the "final" computations, especially of the associated downward continuation problem.

Remove-restore upward continuation

A remove-restore technique has been

applied for handling long wavelengths, as well as for handling topographic effects, mainly affecting the shorter wavelenghts.

The long-wavelength signal has been modelled by the OSU91A spherical harmonic model, evaluated both on ground and aloft (elevation 4 km).

Topography was handled by interpolating a regular free-air anomaly grid from terrain-reduced point value data. A RTM-reduction, conceptually corresponding to a Bouguer reduction to a smooth mean elevation surface of 100 km resolution, has been used. The KMS 5' x 10' digital terrain model used (based on available small-scale maps, satellite altimetry, and airborne radar soundings) incorporates ice (density 0.92) and land (density 2.67) masses, but is of insufficient accuracy and detail to produce reliable, bias-free terrain effects. Systematic errors may be produced by *topographic aliasing* occurring e.g. when the average height of gravity stations is different from the average topograhic height. This is quite common situation in the land/ice nunatak zones, where gravity stations tend to be located on mountain tops since valleys are covered with glaciers. The primary role of the RTM-reduction is to diminish the topographic aliasing, but errors in the used DTM will propagate to the predicted free-air anomalies and thus offset some of the advantage of the terrain reduction. The only way to circumvent this problem is the use of more reliable terrain and ice models, and here the acquired airborne radar profiles may be quite useful in detecting systematic terrain model height errors along the flight tracks.

The topographic- and OSU91A-reduced gravity data have been gridded on a 5' x 10' geographic grid using a fast quadrant-search collocation routine, and, after restoration of the terrain effects, a 9-band spherical FFT upward continuation has been applied as outlined in the previous section. A data grid of 384 x 512 points have been transformed, including a zero-padded border zone to minimize FFT edge effects. After restoration of OSU91A gravity aloft, a final free-air anomaly grid at flight altitude is obtained.

Comparison to the airborne data

For a valid comparison with the airborne gravity data, the predicted free-air anomaly grid aloft has finally been interpolated to the airplane tracks, and submitted to a filtering corresponding to the previously mentioned zero-phase gravimeter filter. This filtering has been carried out as a space-domain convolution, using an empirical impulse response function, determined from passing a delta spike to the airborne gravity processing system.

Since most of Greenland is void of ground gravity data, the predicted filtered free-air data aloft will only be of use in areas of reasonable data coverage. Table 1 presents statistics of comparison for a number of land and coastal areas.

From Table 1 it is seen that the comparison of the measured and modelled gravity aloft ranges from 7 to 16 mgal in standard deviation. The worst results are obtained over land (area A is a very rugged mountainous region), illustrating the topographic aliasing phenomena. Over marine areas the results are better, and it appears that the airborne gravity system is clearly measuring a useful signal, and that it is quite probable that the 5-mgal error estimate of the airborne data is realistic.

More ground data will be required to substantiate this (the ground based survey is thus continuing in selected areas), and especially the survey area at the center of the Greenland ice cap (elevation 3300 m, cf. Forsberg et al, 1992) will be useful for more accurate evaluations due to the limited upward continuation required and the alias-free data terrestrial data collection.

Conclusions

In this paper the first continental-scale airborne gravity project has been outlined. The estimated accuracy (5 mgal at 20 km resolution) will be most useful for geoid determination, mean anomaly prediction and regional geological studies. Preliminary upward continuation attempts by FFT methods have been relatively inconclusive due to uncertainty in the upward continuation. More tests will be carried out as more of the airborne data are processed, and more marine and land gravity data have been collected.

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Table 1. Comparison of airborne and upward continued terrestrial gravity data.

Area	Airborne gravity anomalies (mgal)				Difference airborne - upward continued ground data			
	mean	std.dev	min	max	mean	std.dev	min	max
A: 69.5-71N, 55-51W	-2.4	44.0	-94.6	56.5	13.1	16.7	-30.0	45.2
B: 64-65N, 55-50W	3.2	37.4	-53.6	63.8	3.1	9.2	-21.2	25.4
C: 68-68.8N, 28-23W	23.6	11.2	-3.4	46.2	8.1	7.7	-15.5	30.4
D: 61-62.5N, 55-51W	5.9	21.9	-29.4	42.4	3.2	7.9	-8.0	12.9

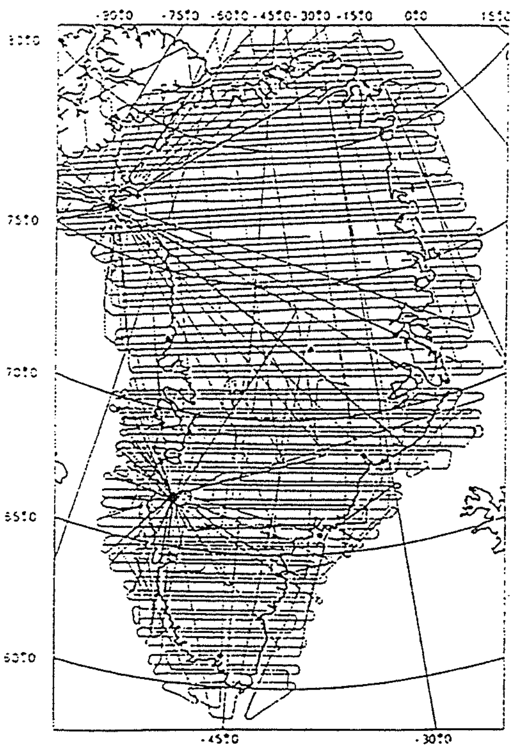

Fig. 1. Tracks of the Greenland aerogeophysical project. GPS tracking sites shown by stars.

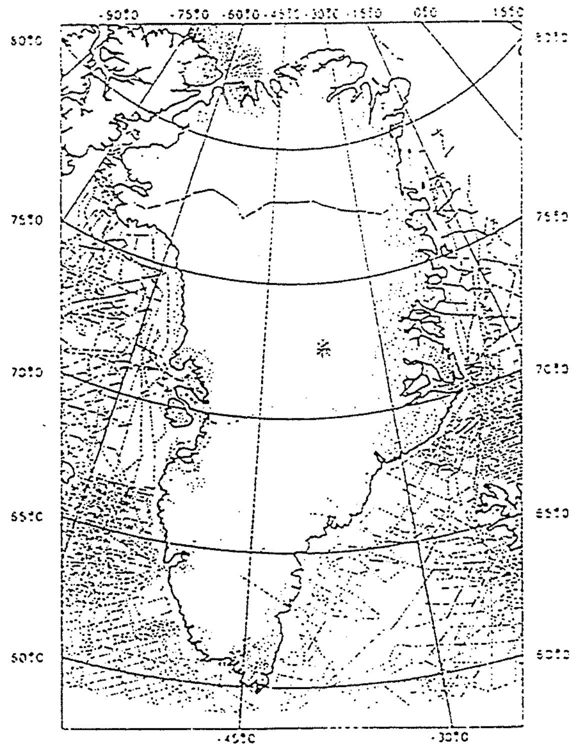

Fig. 2. Distribution of surface gravity data in Greenland.

Sea Gravity Data Adjustment with Program SEAGRA

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presented at the workshop on
Marine Gravity Data Validation,
Toulouse October 27-28, 1992.

Abstract

The sea gravity test data set of 112 693 points distributed by Bureau Gravimetrique International (BGI) in August 1992 to a small group of interested gravimetrists has been adjusted for track biases using a FORTRAN program named SEAGRA. Before the adjustment, tracks had to be defined by a combined distance and azimuth difference criterion between successive points, resulting in 473 tracks. For 430 of these tracks, at least one crossing with other tracks exist. The rms and maximum crossover discrepancy in gravity before adjustment from 1666 crossovers was 27.2 mgal and 189.0 mgal respectively. For these 430 tracks, constant track biases have been adjusted with program SEAGRA yielding in rms and maximum track biases of 27.0 mgal and 102.1 mgal respectively. The rms and maximum crossover discrepancy after adjustment was found to 1.1 mgal and 6.3 mgal respectively, suggesting a very significant improvement of the data quality by adjusting track biases.

1 Introduction

In the past 15 years, much effort has been made to derive gravity anomalies at sea from satellite altimetry, because the satellite altimeter missions GEOS-3, SEASAT-1 and GEOSAT have provided an almost complete coverage of the world's oceans with data. But satellite altimeter derived gravity anomalies are limited in spatial resolution and accuracy to about 10 km and 10 mgal respectively (e.g. BASIC and RAPP 1992). Therefore, sea gravimetry on board of a surface ship is still the major tool for determining the Earth's gravity field at sea with high spatial resolution and accuracy (about 1 km and about 1 mgal). There has been developed a number of different sea gravity meters and mountings on gyro stabilized platforms since 1957 (e.g. TORGE 1989), and the observational procedure is nowadays almost fully automatized.

A limitation of the accuracy was in the early days of sea gravimetry due to the drift of the sea gravimeter, which has been solved in the past years by instrumental improvements. The major limitations of accuracy of sea gravimetry were in the past years due to inaccurate EÖTVÖS corrections because of positioning errors, especially in the open oceans far from the coast, resulting partly in errors of tens of mgals. These limitations could recently be overcome with the GPS positioning system, providing accurate positions all over the world and enabling sea gravity measurements with an accuracy below 1 mgal (e.g. HUSTI and STRANG VAN HEES 1986).

But there exist millions of sea gravity observations stored in the data bases, affected by the above mentioned limitations. A possible method of increasing their overall accuracy is the adjustment of track biases (and tilts), accounting for long wave errors in the observations. WESSEL and WATTS 1988 report a reduction of crossover discrepancies from 22 mgal to 14 mgal by applying bias and tilt corrections determined from about 63 000 crossovers. The purpose of this paper is to present a least squares adjustment program called SEAGRA for the determination of sea gravity track biases, and to describe some results of the application of the program with a test data set of 112 693 points distributed by the BGI. We will show later on, that for the BGI test data set, the gain in accuracy by adjusting track biases is probably much larger than that reported by WESSEL and WATTS 1988.

2 The Program SEAGRA

The basic concept behind the adjustment of sea gravity track biases $b_{(i)}$ is to assume errors beeing almost constant within one track but varying randomly from track to track:

$$l_{(x,y,i)} + v_{(x,y,i)} + b_{(i)} = g_{(x,y)} \tag{1}$$

with x, y = position,
i = track number,
l = observation,
v = residual,
b = track bias,
g = gravity.

If this assumption is not valid for a specific data set, the adjustment of track biases will not make much sense and the overall gain in accuracy by adjusting track biases will probably be small or zero. In a crossing of tracks i and j, the crossover discrepancy $d_{(i,j)}$ can be written as

$$d_{(i,j)} + v_{(i,j)} = l_{(x,y,i)} - l_{(x,y,j)} + v_{(x,y,i)} - v_{(x,y,j)} \tag{2}$$

and

$$d_{(i,j)} + v_{(i,j)} = b_{(j)} - b_{(i)} \tag{3}$$

with $v_{(i,j)}$ = residual crossover discrepancy.

Assuming the track biases b beeing unknown, the track biases can be estimated from a standard least squares adjustment procedure, provided there exist crossings for each track, the number of crossings exceeds the number of tracks, the tracks with crossings form a connected network, and we supply a datum to the adjustment by either constraining the track bias for at least one track to a given value or by using a so called free network adjustment procedure by forcing the square sum of the track biases to minimum, or equivalently the sum of the track biases to zero.

Using this basic concept, a FORTRAN 77 program named SEAGRA had been developped in 1985 for the adjustment of sea gravity data within a project of geoid determination in the North Sea area at the University of Hannover. The program had been developped and tested on a Control Data Cyber 76 with very small RAM (about 1 MByte) and uses therefore storage of the data, observation equations, normal equations etc. on disc. The program is restricted to 5000 tracks and to 5000 points per track. The crossings of the tracks are detected automatically even for non-straight line tracks using a sophisticated algorithm for searching track crossings, allowing for extrapolation over a certain radius (accounting for the situation that one track is very near to another track, but does not exactly cross it). The datum of the adjustment is provided by minimising the square sum of the track biases; for tracks without any detected crossing the track bias is constraint to zero. The track bias adjustment can be carried out for one cruise only (internal crossings) or for a number of different cruises (internal and external crossings). The solution of the normal equations is done with a modified version of routine NES (PODER and TSCHERNING 1973), and there is implemented optionally a re-ordering of the unknowns to obtain minimal profile of the normal equation matrix (SNAY 1976). But this option has not been applied in the tests described in section 4, because the computation time for reduction of the normal equations and solution of the unknowns is very small compared to the total computation time (see Table 1). There is also implemented in the program a comparison of sea gravity data before and after track bias adjustment with reference observations (harbour stations, observations with sea bottom gravimeters, or already adjusted surface sea gravity data). Within the North Sea geoid project, some sea gravity projects were adjusted with the program, but there was little gain in overall accuracy because the errors of the input data were already small. Since that time, the program had been given to four other institutions.

After having received the BGI test data set (see section 3), the program has been implemented on a SUN SPARC 2 workstation under operation system UNIX, and some small modifications were necessary mainly connected with the different word length in single precision on a CDC and under UNIX. After having carried out initial tests with the BGI test data set, a program bug has been detected and subsequently corrected. In the BGI test data set, there exist data with a very small point separation of about 0.01 km (see section 3), which was not the case in the data sets which have been processed so far with the program. Because in the program a crossing was said to be detected, if the crossing point is located within some distance (6 km has been used) to the track, crossover values were partly extrapolated. But extrapolation from two points separated by only 0.01 km to 6 km can create very large extrapolation errors. Therefore the crossover detection algorithm has been modified by allowing extrapolation for the point separation distance within the track at maximum. This modification gave slightly less detected crossings, but dramatically improved the maximum crossover discrepancy after adjustment in the BGI test data set (from 71 mgal to 6 mgal). There has also been added a routine to check the sea gravity observations for anomalous gravity gradients (gross error detection).

3 Preparation of the Test Data Set

The sea gravity test data set of about 17.9 MByte has been made available by BGI on magnetic tape. The data set contains 112 693 records in the EOS format (e.g. BGI 1992), a distribution plot of the data provided by G. Balma from BGI is given with Fig. 1.

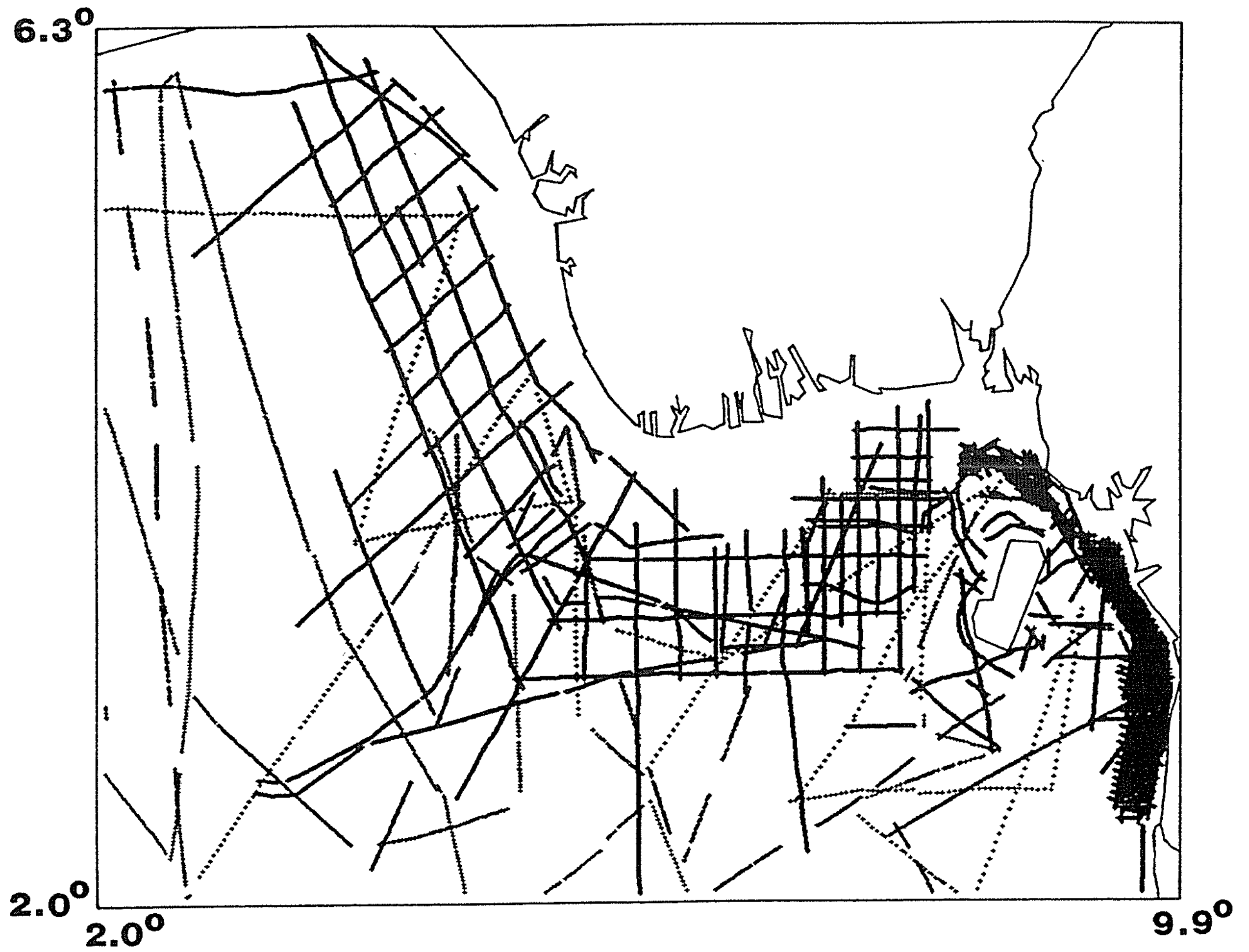

Figure 1: Distribution of sea gravity observations in the BGI test data set

Some initial tests with the data showed, that for some parts of the data no depths were given (the depths were set to zero), which results in partly wrong Bouguer anomalies given on the tape, and that a number of additional informations like date and time of the observation, ship's velocity, EÖTVÖS correction and most important the track number (or leg number named in the EOS format description) were not given respectively set to zero. It should also be mentioned, that there exist partly data with a very small station separation of about 0.01 km, which produced some problems with the application of program SEAGRA (see section 2), and naturally increases the computation time in all computations. I believe, that it is not very sensefull to store sea gravity data at such a high rate because of the lowpass filtering applied on board of the ship, giving highly correlated data for some kilometers). But there has not been applied any decimation of the data in order to enable a comparison with other evaluations of the test data set. Because the track number is a necessary information for program SEAGRA, an algorithm for automatic track identification using the given positions only had to be implemented and tested. After some experiments, the following algorithm was applied (see Fig. 2):

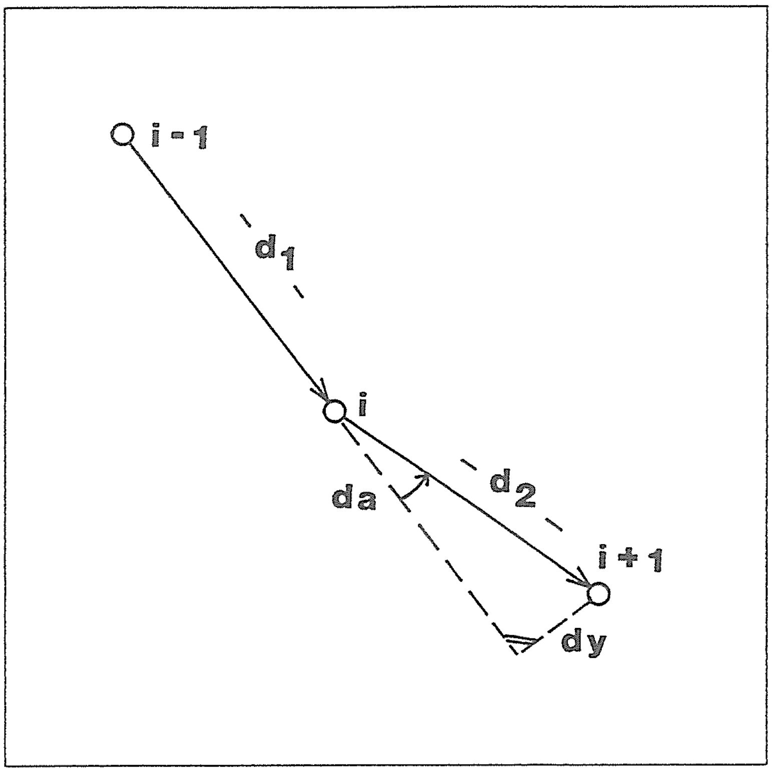

Figure 2: Geometry for track identification procedure

Given three successive points i-1, i and i+1, compute the distance d1 between points i-1 and i and the distance d2 between points i and i+1, and compute the azimuth a1 between points i-1 and i, and the azimuth a2 between points i and i+1. Next compute the azimuth difference da = | a2-a1 |. A new track, starting at point i+1 is defined, if

$$d2 \geq 10 \text{ km, or}$$

$$da \geq 30^0 \text{ and } dy \geq 0.5 \text{ km.}$$

The latter and condition accounts for larger azimuth differences at parts of the data having very small point separation of about 10 m and possibly inaccurate positions.

The above described algorithm has been implemented in program EOSPGA, which simultaneosly carries out the track identification and the transformation from EOS format into PGA format, which is used with program SEAGRA. Using this algorithm, 473 track were identified with at minimum 2 points per track (one track only) and at maximum 2083 points per track, the length of the tracks varying between 0.1 and 280 km. For demonstration, the location of the first 30 tracks is given with Fig. 3 and some parameters of the first 30 tracks are given with Table 2.

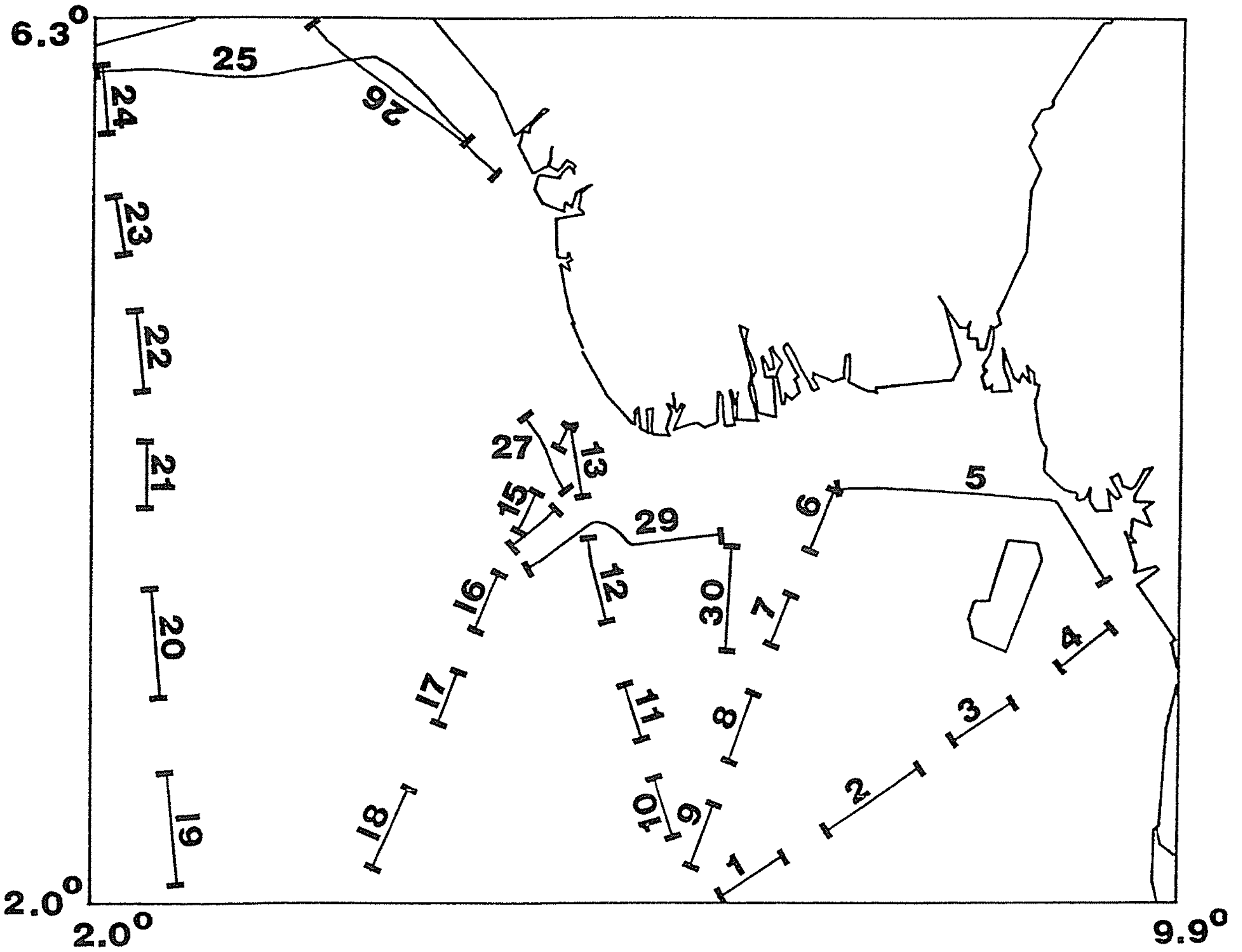

Figure 3: Location of the first 30 identified tracks out of 473 tracks

4 Adjustment of the Test Data Set

After preparing the data set (see section 3), track biases were adjusted with program SEAGRA (see section 2) on a SUN SPARC 2 workstation. There were detected 1666 crossovers, and the rms and maximum crossover discrepancy in gravity before adjustment was 27.2 mgal and 189.0 mgal respectively. For 43 tracks, there could not found a crossing and for these tracks, no bias could be adjusted. The maximum number of crossings was 40 for track no. 264 with a length of 41.1 km. A histogram of the crossover discrepancies before track bias adjustment is given with Fig. 4. For 430 tracks, track biases have been adjusted with rms and maximum track bias of 27.0 mgal and 102.1 mgal respectively. A histogram of the track biases is given with Fig. 5. As can be seen in the histogram, there are at least three groups of tracks, one located around -90 mgal, the second around -10 mgal and the third around +20 mgal track bias. After having corrected the sea gravity data for the adjusted biases, the crossover discrepancies in gravity are reduced to 1.1 mgal rms and 6.3 mgal maximum. A histogram of the crossover discrepancies in gravity after track bias adjustment is shown with Fig. 6. The dramatic reduction of crossover discrepancies after track bias adjustment suggests a very significant improvement of the data quality; however, this should be checked by comparison with independent data, which are not available for the BGI test data set.

5 Conclusions

From the experiment with the BGI test data set it may be concluded, that a very significant improvement of overall accuracy by a factor of about 25 can be achieved by adjusting and correcting for track biases. However, this may hold for old sea gravity data only, because sea gravity measurements with modern instruments applying precise positioning and having accurate harbour connections should not be affected by large systematic errors, as found by other data sets. Nevertheless, it may be important to check sea gravimetry existing in large data bases (e.g. the BGI data base) for track biases as a validation tool of sea gravimetry.

Acknowledgements

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Table 1: Computation time of program SEAGRA for the adjustment of 112693 points in 473 tracks with 1666 crossings

Action	CPU-time [sec]	relative time [%]
input of data	256.7	13.8
searching for crossings	903.6	48.6
computation of normal equations	18.8	1.0
reduction of normal equations	2.4	0.1
computation of unknowns	3.5	0.2
correction of observations	179.0	9.6
computation of residuals	6.9	0.4
output of corrected data	287.2	15.5
others	199.5	10.8
total	1857.6	100.0

The computation time has been measured on a SUN SPARC2 workstation with 4.1 MFLPS.

Table 2: Parameters for the first 30 tracks out of 473 tracks

Track	Start	End	no	length (km)	dmin (km)	dmax (km)	azmin (deg)	azmax (deg)
1	1	52	52	23.807	0.361	1.529	21.571	25.663
2	53	125	73	37.434	0.328	6.256	20.929	29.355
3	126	172	47	23.999	0.416	1.264	22.126	27.610
4	173	214	42	24.444	0.541	1.657	27.527	34.129
5	215	373	159	61.549	0.042	8.405	130.336	181.977
6	374	414	41	34.973	0.391	6.053	235.222	243.481
7	415	450	36	30.583	0.828	1.716	237.489	240.499
8	451	491	41	40.515	0.784	2.162	240.571	242.505
9	492	523	32	37.147	1.074	4.381	240.571	241.640
10	524	560	37	35.185	0.907	2.778	115.085	116.060
11	561	590	30	32.210	1.008	2.184	113.123	116.048
12	591	634	44	48.550	0.907	3.729	100.946	111.272
13	635	677	43	43.054	0.305	1.177	102.811	150.071
14	678	696	19	14.501	0.504	2.266	233.354	236.801
15	697	724	28	24.186	0.864	0.920	233.011	235.750
16	725	762	38	35.542	0.918	0.999	234.681	240.722
17	763	802	40	31.779	0.178	1.021	236.140	256.218
18	803	857	55	48.537	0.884	0.952	233.096	239.585
19	858	912	55	64.737	0.763	2.071	91.663	99.318
20	913	971	59	65.028	1.063	3.272	94.225	98.442
21	972	1029	58	40.792	0.615	2.274	84.712	94.764
22	1030	1075	46	47.792	0.941	3.091	94.641	101.780
23	1076	1107	32	35.020	1.086	2.185	100.606	105.609
24	1108	1156	49	40.013	0.425	1.287	91.611	107.987
25	1157	2598	1442	80.311	0.014	4.753	0.000	357.436
26	2599	3099	501	86.724	0.148	0.227	140.336	156.019
27	3100	3463	364	41.784	0.078	0.145	292.212	328.134
28	3464	3669	206	21.081	0.078	0.125	202.091	216.501
29	3670	4586	917	47.772	0.009	1.070	0.000	356.820
30	4587	4913	327	60.313	0.156	0.203	257.428	273.909

Start: sequence number of first point within the track as given on the tape
End: sequence number of last point within the track as given on the tape
no: number of points located in a track
dmin: minimum distance between successive points
dmax: maximum distance between successive points
azmin: minimum azimuth between successive points
azmax: maximum azimuth between successive points

```
-INFIN...  -100.     43 *
  -100...   -95.      6 .
   -95...   -90.      1 .
   -90...   -85.      1 .
   -85...   -80.      2 .
   -80...   -75.      3 .
   -75...   -70.     27 *
   -70...   -65.      3 .
   -65...   -60.      0 .
   -60...   -55.      3 .
   -55...   -50.      7 .
   -50...   -45.      6 .
   -45...   -40.     18 .
   -40...   -35.     87 ***
   -35...   -30.     29 *
   -30...   -25.     16 .
   -25...   -20.      3 .
   -20...   -15.     11 .
   -15...   -10.      7 .
   -10...    -5.     19 .
    -5...     0.    426 ******************
     0...     5.    915 ****************************************
     5...    10.      7 .
    10...    15.      1 .
    15...    20.      5 .
    20...    25.      1 .
    25...    30.      3 .
    30...    35.      1 .
    35...    40.      0 .
    40...    45.      2 .
    45...    50.      0 .
    50...    55.      0 .
    55...    60.      0 .
    60...    65.      1 .
    65...    70.      4 .
    70...    75.      2 .
    75...    80.      4 .
    80...    85.      1 .
    85...    90.      1 . NUMBER OF SAMPLE VALUES             1666
    90...    95.      0 . MEAN OF SAMPLE VALUES             -7.993 mgal
    95...   100.      0 . MINIMAL SAMPLE VALUE            -189.023 mgal
   100...  INFINITY   0 . MAXIMAL SAMPLE VALUE              86.791 mgal
```

Figure 4: Histogram of crossover discrepancies before adjustment

```
-INFIN...  -100.        0 .
  -100...   -95.        5 *
   -95...   -90.        7 **          group 1
   -90...   -85.        9 ***
   -85...   -80.        3 *
   -80...   -75.        1 .
   -75...   -70.        0 .
   -70...   -65.        0 .
   -65...   -60.        0 .
   -60...   -55.        1 .
   -55...   -50.        0 .
   -50...   -45.        0 .
   -45...   -40.        1 .
   -40...   -35.        1 .
   -35...   -30.        0 .
   -30...   -25.        1 .
   -25...   -20.        4 *
   -20...   -15.       64 ***********************    group 2
   -15...   -10.       18 ******
   -10...    -5.       83 ******************************
    -5...     0.       17 ******
     0...     5.       51 ******************
     5...    10.        6 **
    10...    15.        2 .
    15...    20.      109 ****************************************
    20...    25.       51 ******************       group 3
    25...    30.       16 *****
    30...    35.       15 *****
    35...    40.        6 **
    40...    45.        1 .
    45...    50.        0 .
    50...    55.        0 .
    55...    60.        0 .
    60...    65.        0 .
    65...    70.        0 .
    70...    75.        0 .
    75...    80.        0 .
    80...    85.        0 .
    85...    90.        0 . NUMBER OF SAMPLE VALUES                  473
    90...    95.        0 . MEAN OF SAMPLE VALUES                  0.000 mgal
    95...   100.        0 . MINIMAL SAMPLE VALUE                 -97.094 mgal
   100.0..  INFINITY    1 MAXIMAL SAMPLE VALUE                  102.127 mgal
```

Figure 5: Histogram of adjusted track biases

```
-INFIN...  -100.       0 .
  -100...   -95.       0 .
   -95...   -90.       0 .
   -90...   -85.       0 .
   -85...   -80.       0 .
   -80...   -75.       0 .
   -75...   -70.       0 .
   -70...   -65.       0 .
   -65...   -60.       0 .
   -60...   -55.       0 .
   -55...   -50.       0 .
   -50...   -45.       0 .
   -45...   -40.       0 .
   -40...   -35.       0 .
   -35...   -30.       0 .
   -30...   -25.       0 .
   -25...   -20.       0 .
   -20...   -15.       0 .
   -15...   -10.       0 .
   -10...    -5.       5 .
    -5...     0.     835 *****************************************
     0...     5.     822 ****************************************
     5...    10.       4 .
    10...    15.       0 .
    15...    20.       0 .
    20...    25.       0 .
    25...    30.       0 .
    30...    35.       0 .
    35...    40.       0 .
    40...    45.       0 .
    45...    50.       0 .
    50...    55.       0 .
    55...    60.       0 .
    60...    65.       0 .
    65...    70.       0 .
    70...    75.       0 .
    75...    80.       0 .
    80...    85.       0 .
    85...    90.       0 . NUMBER OF SAMPLE VALUES            1666
    90...    95.       0 . MEAN OF SAMPLE VALUES            -0.051 mgal
    95...   100.       0 . MINIMAL SAMPLE VALUE             -6.299 mgal
   100...  INFINITY    0 . MAXIMAL SAMPLE VALUE              6.311 mgal
```

Figure 6: Histogram of crossover discrepancies after adjustment

BGI Data Validation

Report on the Test Case

John Halpenny - Geological Survey of Canada

Abstract:

A test set of 112,683 gravity stations distributed as part of the BGI marine gravity validation workshop was processed at the Geophysics Division of the Geological Survey of Canada (GSC). The observations were checked, plotted and subjected to crossover analysis. Large crossover differences were reduced by a project adjustment which also brought the data more in line with satellite gravimetry. It appears that further improvement would be possible by checking individual points, but this was not attempted at this time.

Data Input:

The observations were distributed on magnetic tape in the BGI 145 character format, but with many of the fields blank. The first job was to scan all records for format errors. This revealed no errors and also found no extra input in any of the fields. The recomputed anomalies agreed with the given values, except that the density used for seawater was 1.02 rather than 1.03 as is customary at the GSC. The file was reduced to 60 characters per record containing all of the non blank fields and moved to a PC where much of the analysis was performed.

Plotting.

Plots were prepared of free air and Bouguer anomalies and depth at a scale of 1:2,000,000 .These showed some obvious problems as some tracks had large level shifts with respect to others. The shifts were more apparent in the free air than the Bouguer gravity partly because the large continental slope anomaly masked some of the Bouguer offsets and partly because some of the worst data had no depths and did not appear on the Bouguer map. The depth plot looked reasonable, but there may be some problems hidden in the continental slope area. I also plotted page sized tracks of all the projects separately in order to identify them.

Crossovers:

Program 'crosstime' was run on the entire dataset to calculate crossover times. This is a simple program which considers each observation and the one following it as a line segment, and computes the intersection of this segment with any others in the file. Normally the observations are subsampled to produce five minute intervals on the assumption that if the data is part of a line, there are no significant course changes within the interval.

Since this data had no times, the station sequence numbers were used as times and the program was modified to consider a position change of .05 degrees to be a break in the time sequence. All of the 112,693 observations were input, including many that were only a few hundred meters apart. This obviously put a load on the computer to check all these segments, but it required no human work to identify lines, and it produced the complete set of 2653 crossovers shown in Figure 1. The only problem occurred with the very closely spaced observations, where in a few cases the computed crossover point was identical to the segment end point. In these cases, a crossover was calculated for both line segments ending on this point, resulting in duplicate crossover times. This did no harm and the program was later fixed to remove the problem.

Once the 'times' of the crossovers were found, program 'crossval' was used to extract values and compute crossover statistics. Table 1 shows the unadjusted free air crossovers.

Table 1: Unadjusted free air crossovers

min	max	# of crossovers	std. dev. = 32.73
-999.0	-19.00	536************	
-19.00	-17.00	9	
-17.00	-15.00	6	
-15.00	-13.00	5	
-13.00	-11.00	6	
-11.00	-9.00	7	
-9.00	-7.00	6	
-7.00	-5.00	24	
-5.00	-3.00	50*	
-3.00	-1.00	231*****	
-1.00	1.00	1102************************	
1.00	3.00	577*************	
3.00	5.00	30	
5.00	7.00	8	
7.00	9.00	6	
9.00	11.00	1	
11.00	13.00	0	
13.00	15.00	5	
15.00	17.00	2	
17.00	19.00	3	
19.00	999.00	39	

The standard deviation of 32 milligals is due to the more than 500 crossovers with greater than 20 milligal residual, whereas the crossovers of under 20 milligals show a sharp peak around zero. It appears there are two distinct populations, with over 500 'bad' ones and the rest 'good'.

The depth crossovers in table 2 show a similar feature, although here there are only 161 crossovers greater than 19 meters. These may be due to either gross depth errors or position errors. Many, but not all of the large depth residuals correspond to large free air residuals.

Table 2: Depth crossovers

min	max	# of crossovers	std. dev. = 39.02
-999.0	-19.00	104**	
-19.00	-17.00	8	
-17.00	-15.00	3	
-15.00	-13.00	9	
-13.00	-11.00	6	
-11.00	-9.00	13	
-9.00	-7.00	14	
-7.00	-5.00	32	
-5.00	-3.00	84**	
-3.00	-1.00	256******	
-1.00	1.00	1176*******************************	
1.00	3.00	348********	
3.00	5.00	172****	
5.00	7.00	50*	
7.00	9.00	33	
9.00	11.00	22	
11.00	13.00	7	
13.00	15.00	5	
15.00	17.00	3	
17.00	19.00	4	
19.00	999.00	57*	

Since the most obvious source of error is a datum shift by project, the free air residuals were adjusted using a least squares estimation based on project. Normally the datum for an adjustment of this sort is taken from connections to base stations (harbour ties). In this case there were none, so the largest project, project 12, was used as a reference and other projects were adjusted around it. This is obviously an unsatisfactory way of selecting a datum but in this case there was no other information to use.

The first adjustment reduced the crossover standard deviation down to 9 milligals, but the distribution of residuals in some projects did not appear reasonable. The adjustment was rerun using the first output as trial values to reduce the size of the residuals, and a new and slightly different output was produced. It appeared that there was a numeric instability due to the large number of very large crossovers and possibly the very poor structure of the network. The adjustment was recycled 5 times and produced the result shown in table 3.

Table 3: Adjusted Free Air

min	max	# of crossovers	std. dev. = 4.43
-999.0	-19.00	3	
-19.00	-17.00	2	
-17.00	-15.00	2	
-15.00	-13.00	10	
-13.00	-11.00	46*	
-11.00	-9.00	91**	
-9.00	-7.00	82*	
-7.00	-5.00	105**	
-5.00	-3.00	105**	
-3.00	-1.00	287******	
-1.00	1.00	1124*************************	
1.00	3.00	588*************	
3.00	5.00	46*	
5.00	7.00	36	
7.00	9.00	66*	
9.00	11.00	19	
11.00	13.00	19	
13.00	15.00	11	
15.00	17.00	3	
17.00	19.00	1	
19.00	999.00	7	

Four projects had adjustments of over 80 milligals, three were in the range 27 to 33 milligals and the others were less than 18 milligals. The standard deviation was 4.4 milligals and only 10 crossovers out of 2600 were larger than 19 milligals. The number of residuals in the 5 to 20 milligal range has actually increased since values that were once over 20 milligals are now closer to zero but are not as close as the good ones on the original file.

Any further adjustment would involve breaking the projects up into lines or other logical divisions and solving for more unknowns. This would involve many more unknowns and would probably not lead to a large decrease in the 4.4 milligal standard error already achieved. The disadvantage of using more unknowns than are justified is that errors which may be random to start out with are distributed in some arbitrary way throughout the data. In particular, an adjustment treating all of the crossovers as independent unknowns would eliminate the crossover errors but would distribute the noise in a manner which would make the whole dataset suspect.

Satellite gravity:

A 5 minute grid of satellite free air gravity by Haxby was used as a basis of comparison with the ship data. Figure 2 is a plot of the differences between the satellite and ship gravity showing that the mean is roughly zero but differences of up to 40 milligals do occur. All this indicates is that we have approximately the right datum for our adjustment and that, as expected, there are high frequency signals that do not appear in the satellite gravity.

Line edit:

The best way to detect individual bad values is with a visual display. The GSC dynamic meter control system has a general plot facility which operates from the data base generated during meter operation. This same system was used to store the BGI data, although station sequence was used in the time field, and it made possible the display of track data for any part of the project. I did not have the time to go through the file and check all suspicious lumps, but such a step is essential for a final adjustment of any data set.

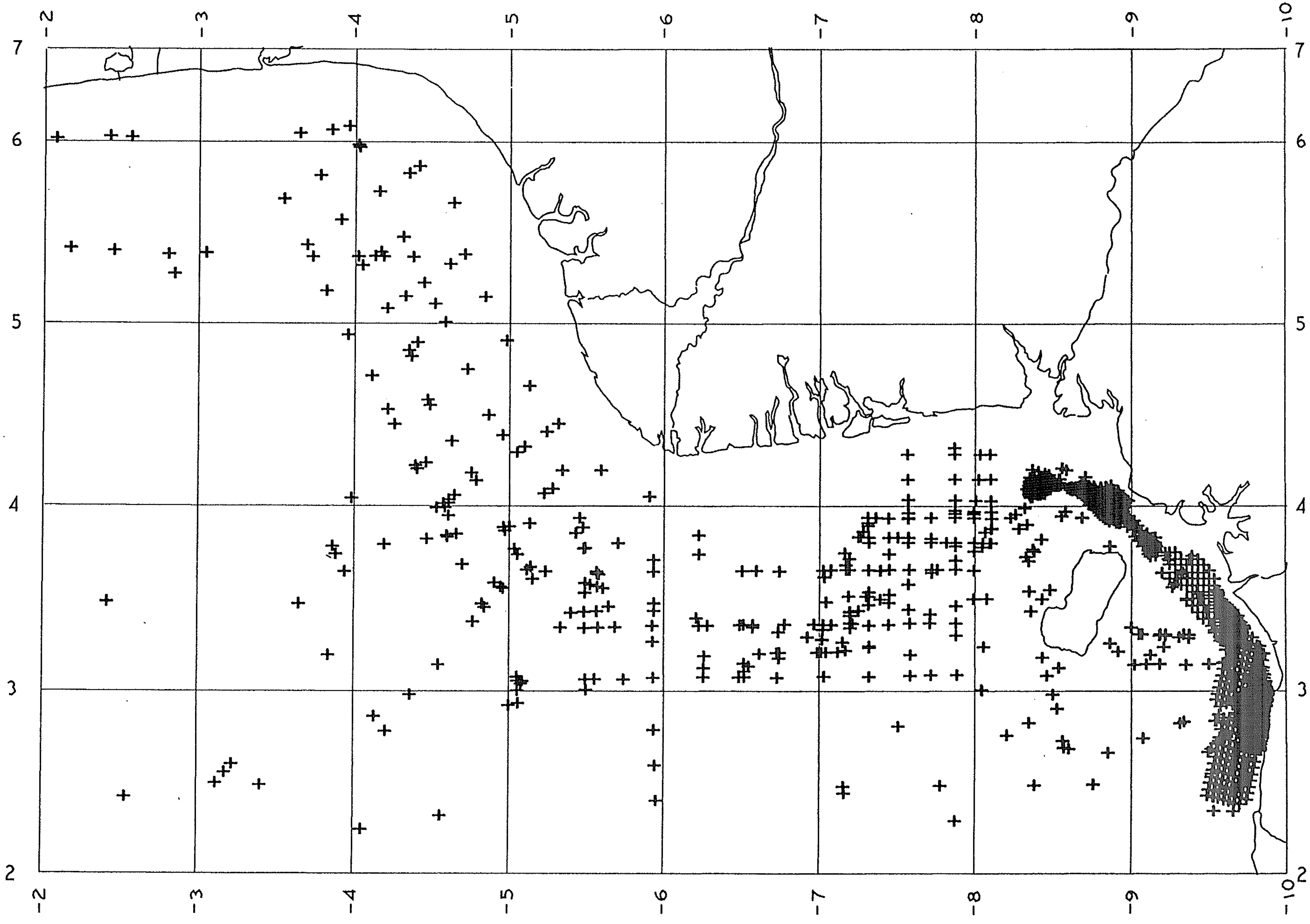
Conclusions:

The BGI test data set was difficult to work with because there were no times and no base values. With no times, we cannot calculate an eotvos correction which can be used to identify turns and spot areas of bad navigation. Without base ties, there is no way to set a datum for the survey. However, the project adjustment removed the major shifts and provided a reasonably homogeneous data set. If further work is to be done, it will involve checking individual lines with our plotting program to remove suspicious parts.

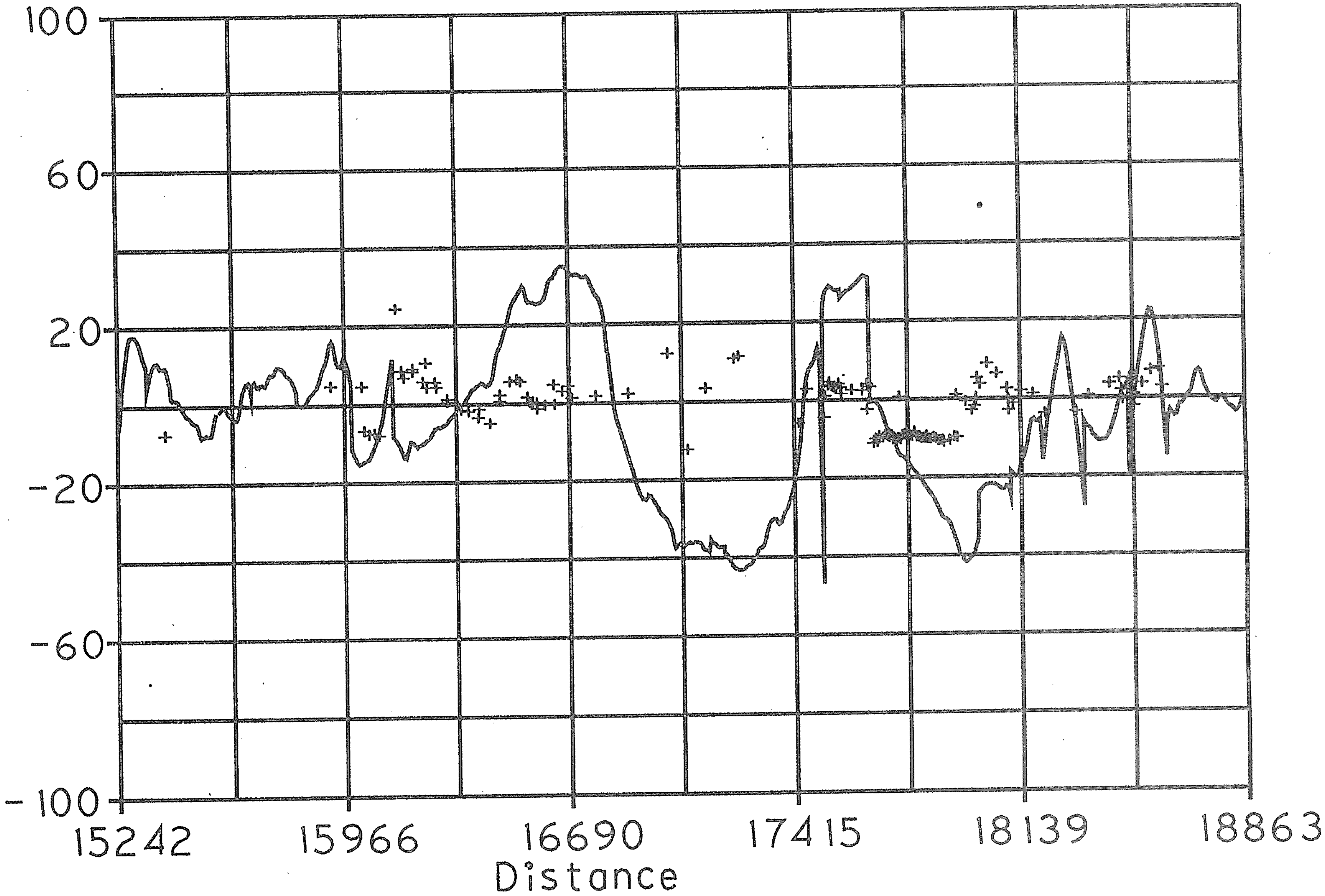
Figures:

Figure 1: Crossovers in the BGI Test Dataset

Figure 2: Difference in milligals between Project 4 and satellite free air. Crossover residuals are also shown.



BGI Test Dataset Crossovers



sat diff F.A. diff

Project 4

A Marine Validation Test Case

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Abstract

A test dataset based on real shipborne gravity data archived at the Bureau Gravimetrique Internationale, Toulouse (BGI) has been internally and externally verified using along track profile analysis, cruise comparison and adjustment by cross-over techniques. The resulting dataset shows significant statistical and visual improvement and application of specially designed validation software has ensured good quality control. Statistically the rms of the external crossovers was reduced from 64.9 mGals with a mean of 40.5 mGals, to 5.5 and -0.01 mGals respectively.

1. Introduction

The eradication of systematic error and minimisation of random errors within shipborne gravity surveys has been the source of lengthy studies. It is commonly accepted that the largest source of error is related to navigational control; data vintage thus holds the key. GPS navigation is only a reality in surveys since the late 1980's. Before then TRANSIT satellites improved upon navigation quality which prior to 1967 was all Celestial. Clearly poor positioning contributes major error in a number of ways, primarily since we may be looking at gravity recorded from two independent points, separated by a variable gravity gradient, yet the navigation suggests that we are looking at the same point on the earths surface. Errors are larger far from land where there is less navigation control, and also where the gravity gradient is high and thus gravity changes markedly over short distance.

Incorrect Eotvos adjustment is recognised as one of the major sources of error, again accurate ship velocity and heading must be known as well as latitudinal position. The exact parameters may not be well controlled as separate navigation and gravimetry measurements are synthesized by interpolation into a "data record". There is often a good case for dismissing shipborne data recorded about a turn and a period of 10 minutes extra to allow for the gravimeter to restabilise. Vintage data is clearly vulnerable to mis-calculation.

Other sources of random error are due to cross-coupling and off-levelling. This is a function of sea-state and the ship heading and is very difficult to compensate. Other sorts of shipborne error reflect incorrect base ties and variable geoid reduction. These latter variables can provide very large cross-over discrepancies but can be readily removed following cross-over analysis.

Even after making some adjustments for systematic errors and minimising random error content there is a residual error that is recognised in the corrected crossover information. We can only attempt to keep this error component to a minimum, the accumulated problems of navigation mislocations and instrument accuracy are now an inherent and unavoidable feature of worldwide gravity databases.

2. MARVALID and COE Software

Specially designed software has been developed in Leeds using XVIEW in OPENWINDOWS to provide a rapid validation tool geared towards the thorough evaluation of large datasets.Two packages have currently been produced with important linkage between them, enabling rapid validation and assessment of tilt and bias corrections.

MARVALID provides a three window display showing along track profiles of Free-air gravity with bathymetry and Eotvos correction, a map distribution window and a text window. The skilled user is able to drag along the profile and search for spurious datapoints, steps, poor bathymetry correlation, strong gravity-heading correlation and so on. A chosen point is searched automatically in the other windows allowing rapid search and edit of rogues. The converse search operations are enabled from the other two windows. Automatic gradient and range "finds" provide an automatic problem search to the technique, enhanced by a variety of zoom and window operations. Dependent on the size and complexity of the examined leg the user can work through rapidly and thoroughly in a number of minutes and maximise the quality of this "internal" validation.

COE has been designed as a means of external validation, whereby a cruise is compared to the rest of the database as a means of assessment. There are a variety of windowed outputs including a text window displaying all the cross-over locations and discrepancies, a map distribution window displaying the cruise and all crossing cruises, and there is a Cross-Over Plot window showing cross-overs against time for each cruise. The user can display cross-overs in this window before and after cross-over corrections have been applied and hence assess improvements. Clicking on a large residual cross-over achieves an automatic search in the MARVALID environment for both of the cruises involved in the crossing. See Figure 1.

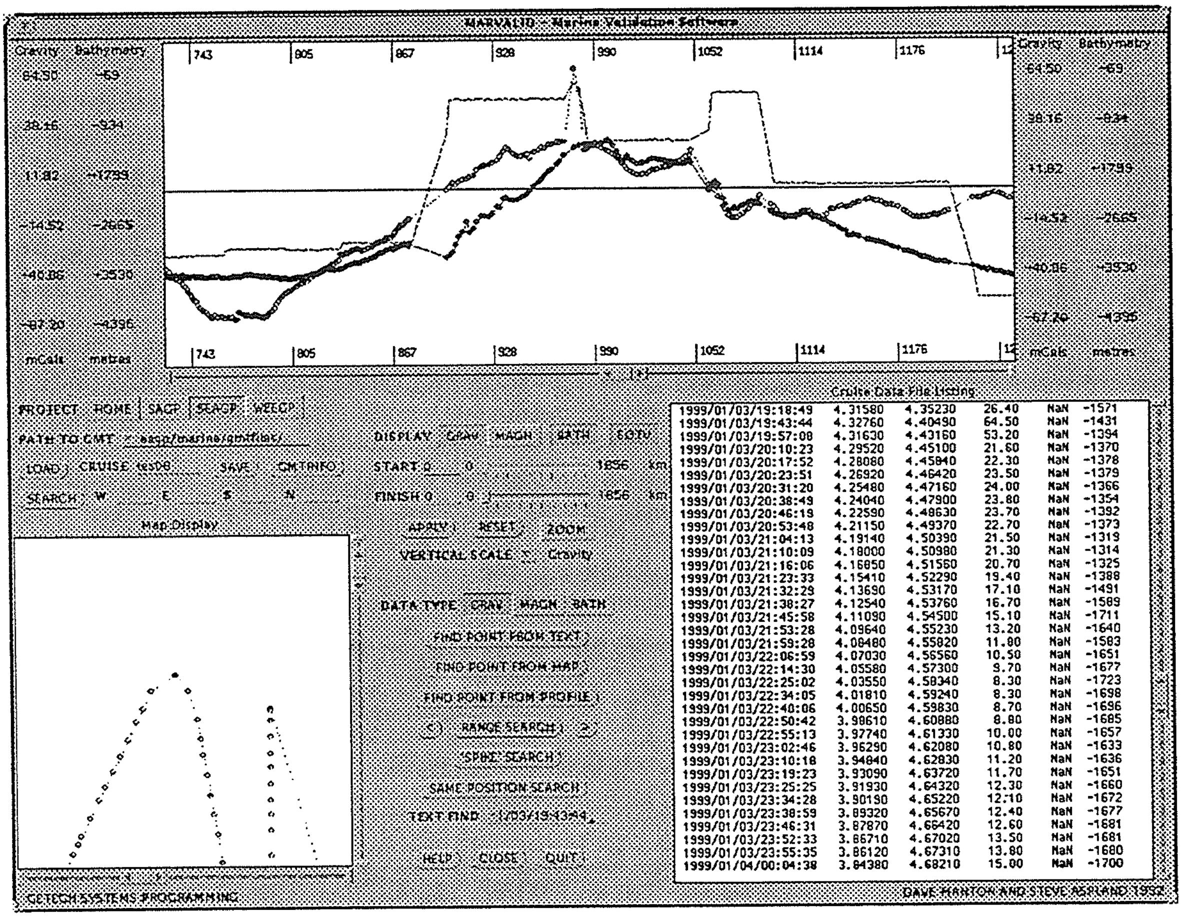


Fig 1: "Internal" Along Track Verification using MARVALID. Notice the large gravity rogue at 990 km, correlating with the ship turn.

3. Cross Over Calculation

The cross over analysis algorithms used in this test case are based on those written by Wessel and Watts (1988) for the global adjustment at Lamont-Doherty Geological Observatory. The software reads so-called bin index files containing all the vital information about the shipborne data written to binary "GMT" datafiles. Locational bins where two legs both occur are examined more closely for possible crossings. Cross-overs are interpolated only between pairs of points that are less than 10 minutes of recording time apart (roughly equivalent to 3 km) Linear interpolation is used to determine the gravity values at the cross-over point, producing "internal" crossovers between segments of the same cruise and "external" crossovers between segments of different cruises. A file containing all the pertinent cross-over information is accessed by a matrix inversion procedure developed in Leeds that minimizes the errors and achieves a series of best fit corrections for each constituent leg with crossovers.

The software allows the calculation of tilt corrections but in the case of datasets with non real times instrument drift calculation is considered inappropriate. See figure 2.

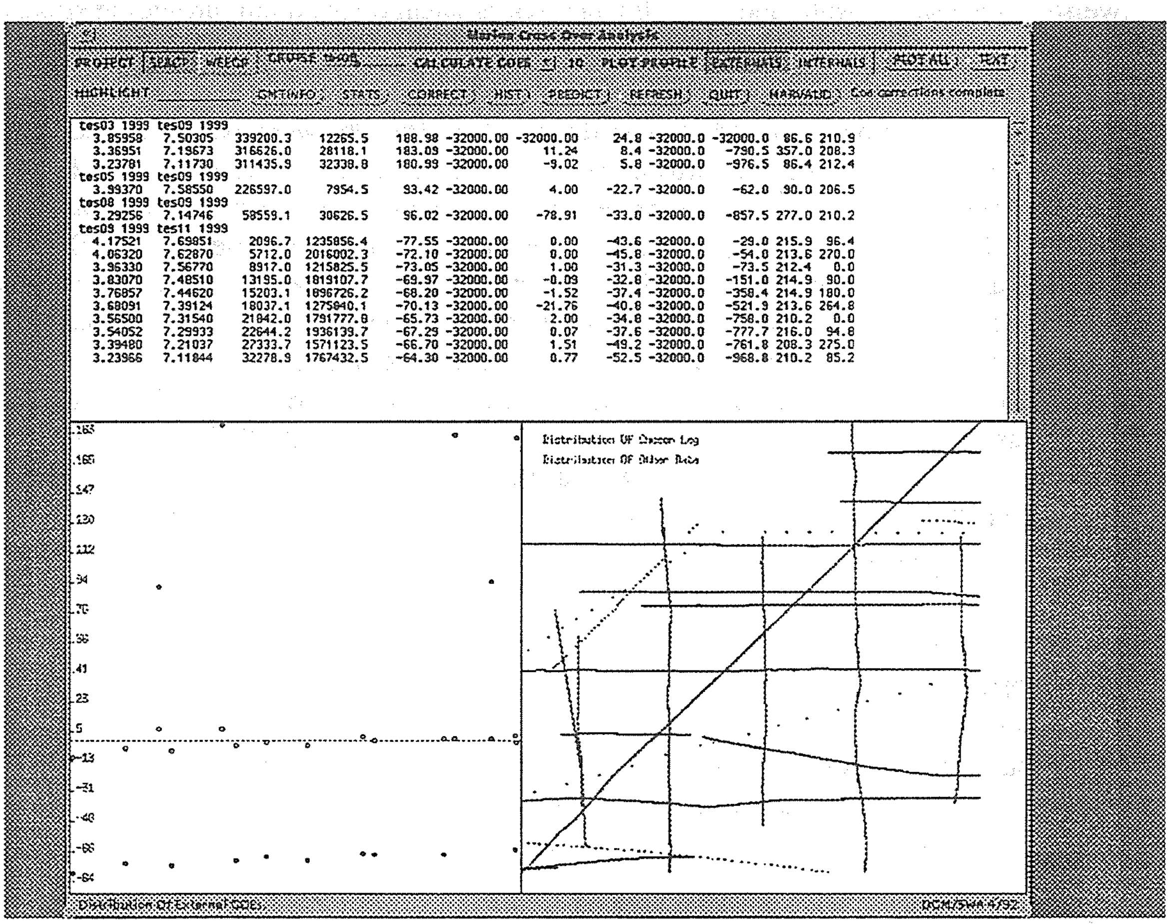


Figure 2: External Validation of tes05 using COE analysis. Notice the improvements due to Cross-over adjustment shown in bottom left window (Filled circles: before Circles: after correction)

4. The Test Case

The BGI test dataset comprised 112,693 points provided in their new EOS format. The dataset provided a very real example of the sort of problems common in the validation of large datasets, whereby only very minimal information is provided. Important information on dates, real times, Eotvos corrections, navigation systems and more were all absent leaving only the minimum of geodetic location, gravity and usually bathymetry. This lack of information deters from some valuable controls that may be enabled in fully documented datasets. Nevertheless the application of so-called dummy times and pseudo-Eotvos corrections provide an alternative validation control.

Dummy times are calculated based on a constant ship speed of 12 knots. The actual ship speed is of course variant but the technique enables the determination of a ship heading dependent pseudo-Eotvos correction. That is to say the pseudo-Eotvos is a function of changes of ship heading and is therefore significant in the search for badly applied Eotvos corrections, one of the largest sources of shipborne error.

The positions, gravity and bathymetry are stored together with dummy times into a file in binary "GMT" format (the system adopted by Leeds, based on the original Global Adjustment by Wessel and Watts, 1988, LDGO). The "GMT-system" provides a rapid access system whereby all pertinent information is stored in a series of binary bins with consequent rapid information retrieval.

The test dataset was split into the fifteen constituent cruises and placed in GMT format. The twelfth cruise was re-split due to its dipolar geographical distribution, providing sixteen cruises in all. The size and character of the sixteen cruises varies markedly. Details of the individual legs are given in Appendix A.

Each leg was examined using MARVALID and COE. Profiles were examined and spurious points removed based on the internal performance and performance with other cruises. It was noted that many problems occured within the sixteen cruises, (including outliers, Eotvos correlated sections, tares and bathymetry rogues). These problems were found by internal profile examination. Looking at the crossovers provided a further control in the assessment of systematic errors. Whereas rogues do not affect the cross-over analysis unless they are coincident upon a track cross-over, systematic errors and track biases are not recognised by internal along-track control alone. This outlines the need for the dual approach. Along track techniques of MARVALID resolve as much of the visible random error as is possible and COE techniques, eradicate the systematic shifts due to poor or incorrect base-ties, inconsistent geoid calculations etc. In the test case dataset there were both considerable "internal" errors and major "external" track biases of the order of 100 mGals.

5. Final Adjustment

From Appendix 1 it is clear that both internal and external verification are vital.

Not only is there a statistical improvement in the cross-over statistics but the validation techniques have ensured that residual errors are minimal and that changes between the gravity recorded in two cruises is due to changes in the actual gravity field and not differences in the processing sequences of the two datasets. Details of the bias adjustments are given in appendix B.

6. Conclusions

From the gridded solutions before and after validation (figs 3 and 4) the need for good validation techniques is exemplified. Ideally a fully automatic technique could eradicate all potential data problems but at this stage the subtleties of marine validation have detracted from such a tool. A technique has been developed here to best maximise the efficiency of a skilled operator validation search.

References

Wessel and Watts: Journal of Geophysical Research 93. 393-413
The Accuracy of Marine Gravity Measurements" 1988

Figure 3: Test area contoured at 5 mGals before validation and bias adjustment.

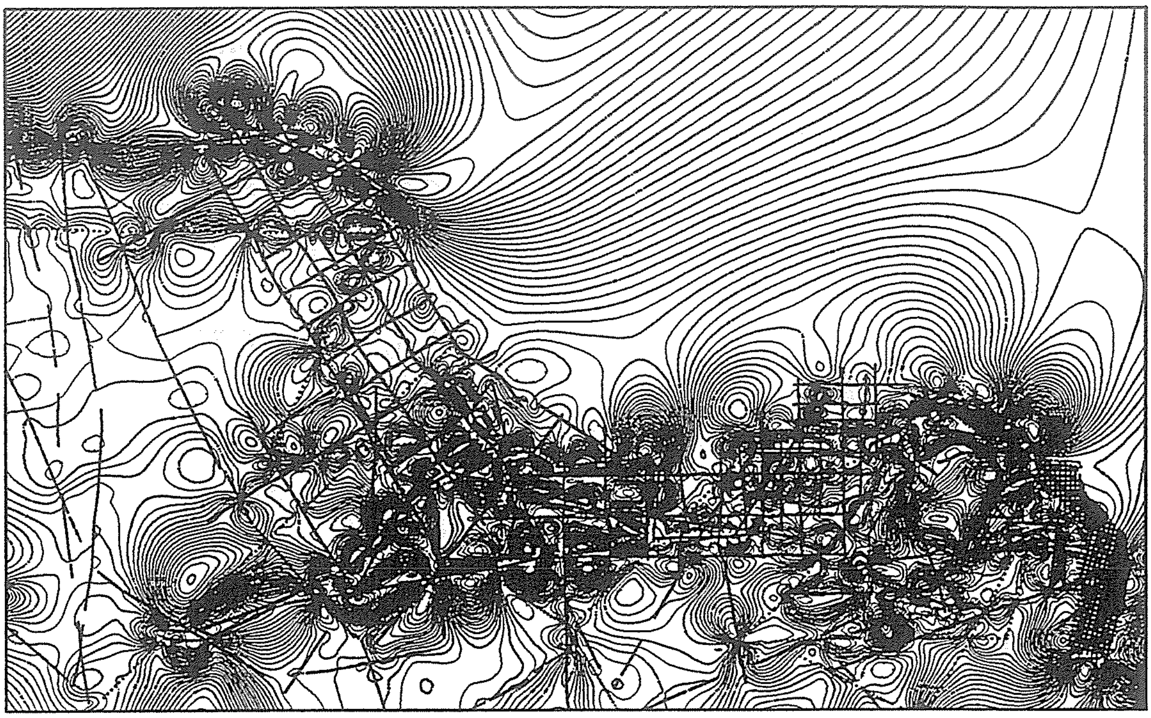
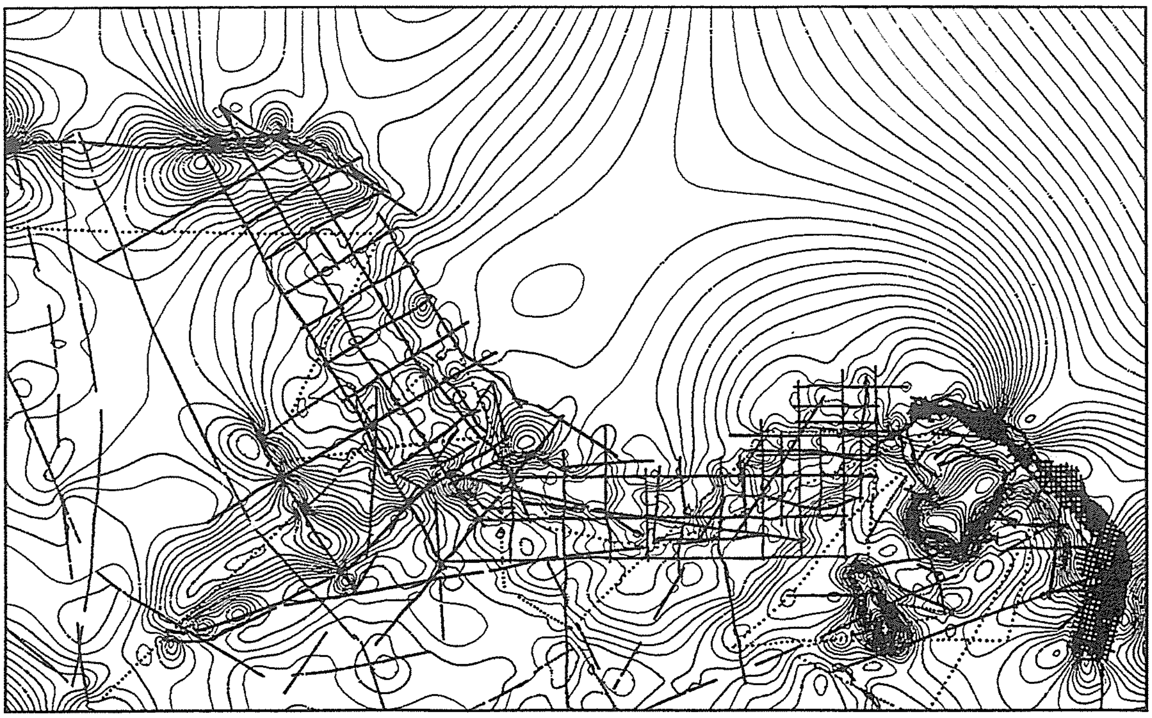


Figure 4: Test area contoured at 5 mGals after validation and bias validation.



Test Case Cross Over Statistics

(BEFORE CORRECTION)

CRUISE NUMBER	NUMBER COES	MEAN	RMS
tes01	40	-5.67	40.07
tes02	8	109.57	13.82
tes03	86	104.28	24.85
tes04	107	95.31	21.62
tes05	17	-17.30	56.25
tes07	15	15.85	41.70
tes08	15	3.20	53.89
tes09	15	-95.83	46.77
tes10	22	-15.07	36.15
tes11	82	-65.72	64.96
tes12	68	-31.40	56.63
tes13	198	-56.03	38.10
tes14	2	28.37	0.00
tes16	137	3.82	51.92
n = 406	Mean = 40.56		RMS = 64.94

(AFTER CORRECTION)

CRUISE NUMBER	NUMBER COES	MEAN	RMS
tes01	40	0.00	5.60
tes02	8	2.64	9.02
tes03	86	1.23	7.38
tes04	107	0.36	4.45
tes05	17	2.65	5.27
tes07	15	2.35	4.78
tes08	15	-0.36	9.52
tes09	15	-2.06	3.94
tes10	22	-1.57	4.26
tes11	82	-2.92	6.53
tes12	68	2.94	6.24
tes13	198	-3.32	2.66
tes14	2	0.37	0.00
tes16	137	3.81	1.45
n = 406	Mean = -0.01		RMS = 5.54

The following bias corrections were applied to the test dataset:

tes01	-22.82
tes02	79.96
tes03	82.58
tes04	74.96
tes05	-13.19
tes07	-3.50
tes08	-4.68
tes09	-98.77
tes10	-35.42
tes11	-30.49
tes12	-7.62
tes13	-36.62
tes14	-2.49
tes16	-2.40

BGI WORKSHOP

VALIDATION OF MARINE GRAVITY DATA

Toulouse (France, October 27-28, 1992)

VALIDATION METHODS AT BGI and APPLICATION TO A TEST CASE

A. Adjaout, M. Sarrailh

INTRODUCTION

In recent years a number of Geologic, Geodetic and Geophysical applications have stressed the need for a selfconsistent globally adjusted marine gravity data set. At B.G.I there is a bank of marine gravity data collected from all over the world since 1940 by different agencies using various apparatuses and positioning systems .

The accuracy of marine gravity data depends for a great part on the quality of ship navigation. The major error source is due to a wrong Eötvös correction, which is function of the ship's heading and velocity and we know that, before 1967, the Loran system was used in coastal navigation and might be considered of sufficient accuracy, whereas at sea most ships used celestial navigation leading to large errors in position.

In addition to these errors, there are errors which depend on the type of gravimeter used, such as cross-coupling, off-leveling and non linear drift effects...

Furthermore it happens that for some of those measurements, additional information such as time, velocity or depth is missing, and in that case the correlation between gravity and bathymetry or the Eötvös effect cannot be studied and used for correcting the data.

At B.G.I we developped a general method to validate marine gravity measurements, based on the analysis of the discrepancies at crossovers.

Figure 1 shows the scheme of the method. In the present paper both the method and the application to a test case will be given.

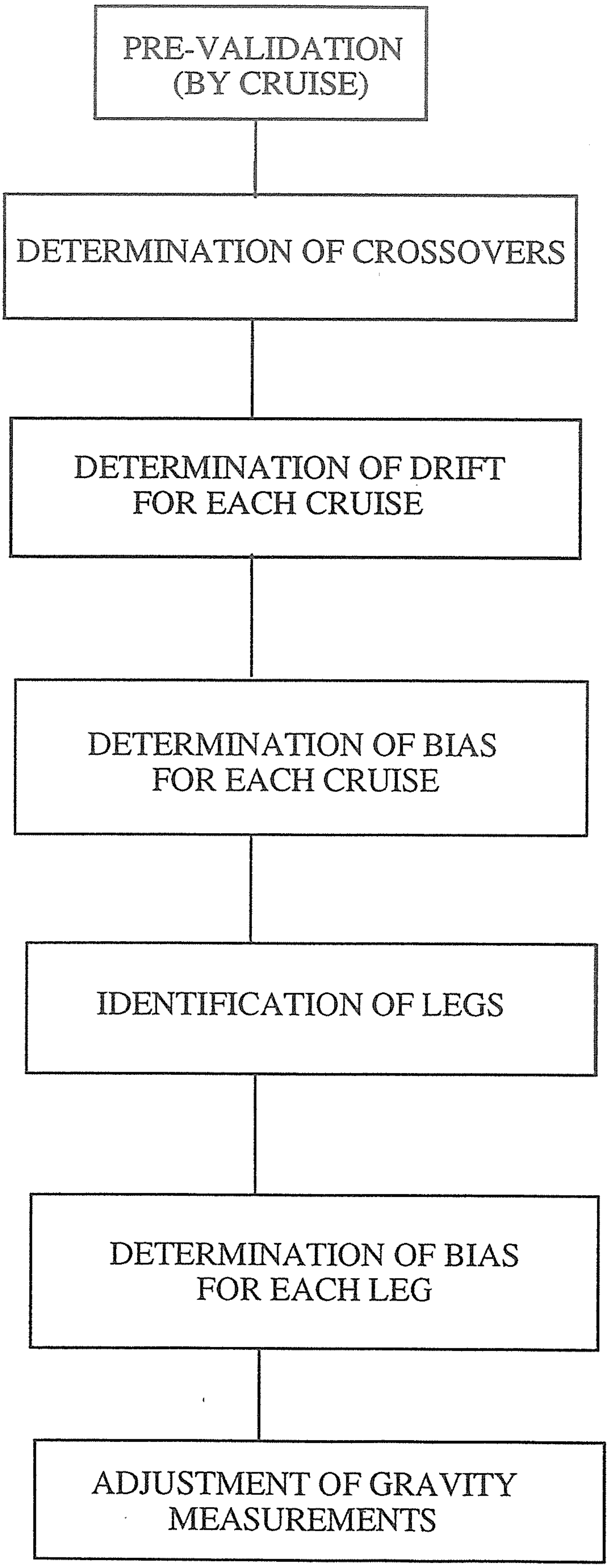


Figure 1: The different steps of the

1.1. PREVALIDATION

This first step of the validation of sea gravity data is used to identify isolated erroneous points (such as spikes). Since the measurements are spatially correlated, we can compare the observed value and a predicted value determined from the neighbouring measurements. The prediction is based on least squares collocation techniques, which not only provides a predicted value but also an estimate of the prediction error.

This package is not much different from the one used for the land data :

- since we suppose that the statistical properties are homogeneous over the area covered by the data, we need first to remove the regional field using either a polynomial or a moving average or a spherical harmonics model.

- then we select the neighbouring points used for prediction. For sea data, we can consider only the points belonging to the same cruise, on the same track where lies the point we select, preceeding or following it (in time).

- we assume that the covariance function has the form :

$$C(\psi) = C_o(1+\psi/\alpha)\,e^{-\psi/\alpha}$$

where : C_O = local variance (it is updated locally)
ψ = spherical distance between points
α = correlation distance multiplied by 0.595 (fixed as parameter, typically 20-25 km)

- at a point P, the predicted anomaly is :

$$\Delta g_P = \sum_{i=1}^{n} a_i\,\Delta g_i$$

where $a_i = \{C_{iP}\}^T\{C_{ij}+D_{ij}\}^{-1}$

with C_{iP} : the covariance between the observation i and the predicted value at P
C_{ij} : the covariance matrix of the observations
D_{ij} : the covariance matrix of the observation errors (associated to the points i and j) ; in practice it is a diagonal matrix.

The error estimate is then computed as :

$$\sigma_P^2(obs.-pred.) = C_o - \{C_{iP}\}^T\{C_{ij}+D_{ij}\}^{-1}\{C_{jP}\}$$

A measurement will be rejected or considered doubtful if the difference between the predicted and the observed value is larger than a given limit and than $k \times \sigma_P(obs.-pred.)$ (where κ is a factor selected by the user, typically 2 or 3).

The package includes a decontamination module. All the points at a given distance from the selected point are used for prediction , even if they are then considered to be doubtful ; in this last case, they can very much contaminate the predicted value. To avoid such effects we sort the doubtful points and we again predict the Δg-values at these points and neighbouring ones, without taking into account the doubtful points.

1.2. DETERMINATION OF CROSSOVERS

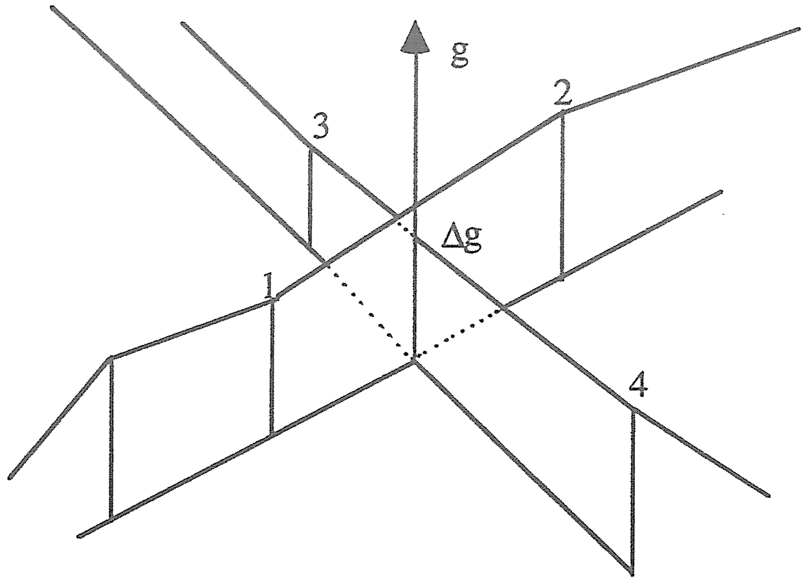


Figure 2 : The geometry of a crossover difference

The two directions 1-2 and 3-4 (fig.2) may pertain to cruises or legs (cf.1-5). g_o and g_o' are the values of gravity at the intersection computed along the first and the second direction by linear interpolation, that is:

$$g_o = g_1 + (g_2 - g_1) \times \frac{D_{10}}{D_{12}} \quad (1)$$

$$g_o' = g_3 + (g_4 - g_3) \times \frac{D_{30}}{D_{34}} \quad (2)$$

where D_{jk} is the distance between the j.th and k.th points.

$\Delta g = g_o' - g_o$ is the crossover error which enables us to write the observation equation. We try to minimize all such errors over the studied area.The crossover is considered if the distance between sequential measurements is less than a given threshold.
To each crossover equation we associate a weight "p" which is computed by taking account of individual error measurements, and of navigation error by transforming the error of position in an error of gravity using its equivalent Bouguer anomaly error. Let us define the following quantities:

$\varepsilon_p, \varepsilon_{p'}$: precision of positioning in the dirctions 1-2 and 3-4

$\varepsilon_g, \varepsilon_{g'}$: precision of gravity measurement in the directions 1-2 and 3-4

$$grad\ H = \frac{H_2 - H_1}{D_{12}}$$

$$grad\ H' = \frac{H_4 - H_3}{D_{34}}$$

(where H is the depth)

$$\Delta H = grad\ H \times \varepsilon_p$$

$$\Delta H' = grad\ H' \times \varepsilon_{p'}$$

Then we define :

$$\delta g = 0,0419 \times 1,67 \times \max(/\Delta H/,/\Delta H') \tag{3}$$

from which :

$$\sigma = \max(\delta g, \varepsilon_g, \varepsilon_{g'})$$

The weight is $p = 1/\sigma^2.\sqrt{p}$ multiplies each observation equation and if one of the four measurements was flagged by the prevalidation procedure doubtful then $\sigma' = k.\sigma$ where *k is a* fixed value.

1.3. DETERMINATION OF DRIFT FOR EACH CRUISE

In general gravimeters have a noticeable drift after a long time of observation . This information may be extracted when the cruise crosses itself. To determine this drift we must have a lot of internal crossovers, a good distribution of those crossovers along the cruise and the interval of time between two successive passes at the intersection must be larger than a threshold. The observation equations are :

$$g_{i,k} = R_{i,k} + D_i . t_{i,k} \tag{4}$$

with :

k : measurement number
i : cruise number
g : true gravity
R : observation
D : drift
t : time from arbitrary origin

Therefore, each internal crossover discrepancy Δg leads to :

$$D_i, \Delta t_{k,k'} = \Delta g_{k,k'} + V_{k,k'} \tag{5}$$

where : Δt is the interval of time at the intersection
$V_{k,k'}$ is the residual

That is we have the observation equations :

$$\sqrt{p_k}(D_i, \Delta t_{k,k'}) = \sqrt{p_k}\Delta g_{k,k'} \tag{6}$$

or, in matrix

$$\sqrt{P}AD = \sqrt{P}G \tag{7}$$

The least squares solution of these is :

$$D = (A^T PA)^{-1}.A^T PG \tag{8}$$

1.4. DETERMINATION OF BIAS FOR EACH CRUISE

Crossover errors between cruises are, in general, due to poor tie-ins at base stations at the start or/and the end of the cruise. The relevant crossovers are called external crossovers. The gravity is written :

$$g_{k,j} = R_{k,j} + b_j \tag{9}$$

with :

k : measurement number
j : cruise number
R : observation already corrected from drift (if determined)
b : bias of cruise number j

External crossover discrepancy between cruise i and j leads to :

$$b_i - b_j = \Delta g_{i,j} + v_{i,j} \quad (10)$$

($v_{i,j}$ is the residual), that is to the observation equation :

$$\sqrt{p_{i,j}}(b_j - b_i) = \Delta g_{i,j}\sqrt{p_{i,j}} \quad (11)$$

One, or some of the biases, may be constrained if ties have been done properly for one or some cruises. If not, the following empirical constraint must be applied :

$$\sum_i b_i = 0 \quad (12)$$

1.5. IDENTIFICATION OF LEGS

As noted by Talwani "the errors due to wrong Eötvös corrections as well as due to cross-coupling, remain constant so long as the ship's heading, as well as the sea state, remain constant". This suggests that constant corrections could be made to individual legs to reduce crossover errors. To find the legs we used one or a combination of the criterias below :

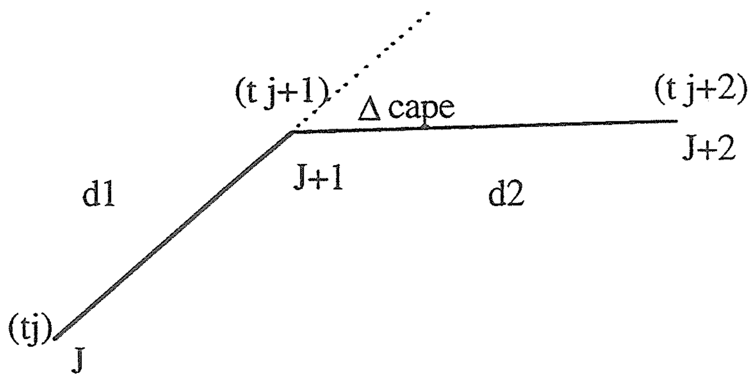


Figure 3: Quantities used in the identification of legs.

j, j+1 and *j+2* being the indexes of sequential measurements (fig.3), we define a new leg according to one of the following conditions :

* Time criteria : $\Delta t >$ fixed value ($\approx$ 15 min) where $\Delta t = t_{j+2} - t_{j+1}$
* Distance criteria : $d2 >$ fixed distance ($\approx$ 5-10 km)
* Cape criteria :
  if c1 is the azimuth between j and j+1, and c2 the azimuth between j+1 and j+2, the condition is :
  Δ cape =/ c1-c2 / > fixed value ($\approx 30°$)
  Whichever criteria is used, we add a condition of minimum number of points per leg ($\approx$ 10)
* Average cape criteria :

This criteria is used to merge some short legs and solve the problem of legs without crossover.

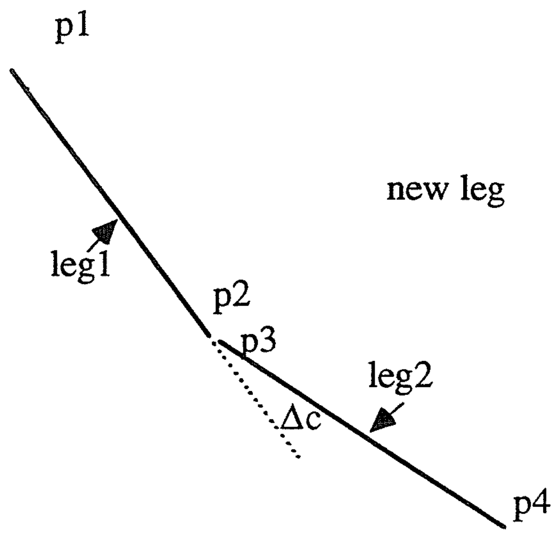


Figure 4 : The problem of merging legs

If p1-p2 and p3-p4 are legs (fig.4), approximated by the segment joining the first and the last points, and if c1 is the cape between p1 and p2, and c2 the cape between p3 and p4, then if /c2-c1/ is smaller than a fixed value (≈ 30°), then leg1 and leg2 are merged into a single leg.

1.6. DETERMINATION OF BIAS FOR EACH LEG

In addition to internal and external crossovers, we use extrapolated information to insure continuity between sequential legs (fig.5).

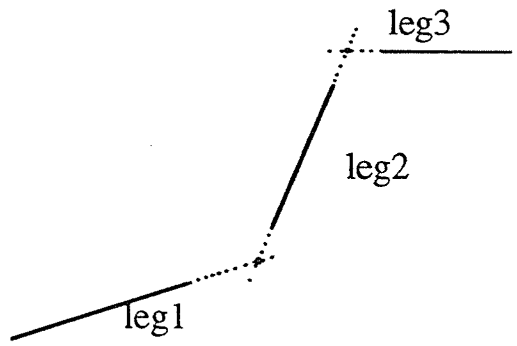


Figure 5 :Extrapolation between legs

The true gravity is written as :

$$g_{k,l} = R_{k,l} + L_l \tag{13}$$

where:

k : measurement number
L :bias of leg number l
R: observation already corrected from drift and bias per cruise (if determined).

* For the extrapolation case we write:

$$L_{l+1} - L_l = \Delta g_{l,l'} + V_{l,l'} \tag{14}$$

*At an intersection we have:

$$L_j - L_i = \Delta g_{j,i} + V_{j,i} \tag{15}$$

* Those equations are solved with the additional constraint:

$$\sum_i L_i = 0 \tag{16}$$

The resulting linear system :

$$\sqrt{P}\, AL = \sqrt{P}\, G$$

is solved by least squares.

1.7. FINAL ADJUSTMENT

In this step we correct all observations with the formula :

$$g_{i,k} = R_{i,k} + D_i . t_{i,k} + b_i + L_{i,j} \tag{17}$$

where

i : cruise number
j : leg number
k : observation number
R : observation
D : drift
t : time from port
b : bias of cruise
L : bias of leg

2. TEST CASE

Figure 6 shows the data set which was distributed by B.G.I in E.O.S format to be validated as test case. There are 15 cruises with 112693 measurements carried out in the Gulf of Guinea. A first inspection shows that, for most of the measurements, there is no information about time, depth, velocity and Eötvös correction, and the distance between points range from 0.1 km to more than 6 km.

This data set is an example of usual difficulties encountered in the validation process, because one cannot choose a reference cruise to compute a bias for each cruise and, without time, the computation of drift is generally inaccurate.

2.1. PREPARATION OF DATA SET

The collocation software was activated in the prevalidation step (table 1), with 5 mgal for the r.m.s error estimate. We found only 6 measurements doubtful and 2 measurements lapsed. It seems then that the data set is internally consistent (in each cruise). Because time was not given, a pseudo-time was generated to compute drifts, the magnitude of velocity used was 10 m/s.

The algorithm of determination of crossovers found 2332 crossovers (with the maximum distance of a crossover to the neighbouring points set at 6 km). The r.m.s and mean of crossover discrepancies before adjustment were 32.4 mgal and 12.6 mgal respectively.

2.2. DETERMINATION OF DRIFT

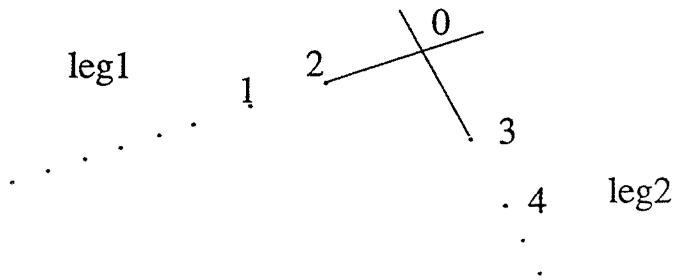
Among the 2332 crossovers, there are over 1800 internal crossovers but only the crossovers for which the interval of time between the two successive passes was larger than 1 day were selected. Table 2 gives the result of the drift adjustment. Internal crossover errors of cruise number 11,before and after correction, were plotted as function of the time interval (fig 7).

2.3. DETERMINATION OF BIAS FOR EACH CRUISE

The maximum bias value is found for cruise number 9 with magnitude 106.12 mgal (table 3 gives the result for each cruise). If we look at the plot of external crossover errors of cruise number 11(fig 8), we notice that we have four groups of crossover errors, one located around 110 mgal, the second around 45 mgal, the third around -20 mgal and the fourth around -87 mgal; this results from the intersection of cruise number 11 with numerous other cruises which were badly tied-in at the start and the end of the cruise. It is therefore necessary to have a reference to compute a meaningful bias for each cruise.

2.4. IDENTIFICATION OF LEGS AND COMPUTATION OF BIAS FOR EACH CRUSE

Using the cape criteria (cf 1-5) with a threshold of 30°, we found 490 legs where only 16 legs were without crossovers. The maximum leg bias found is around 15 mgal. To insure the continuity between legs, extrapolations were done (cf 1-6). Only 40 such points were found, the criteria to select these points being different from the one used to select intersections. This example explains this criteria :



If D_{ij} is the distance between point i and point j, the extrapolation will be rejected if:

* D_{12} or $D_{34} > 6$ km
* $D_{20} > 2.\ D_{12}$
* $D_{30} > 2.\ D_{34}$

2.5. CONCLUSIONS

After adjustment the r.m.s of crossover differences was reduced to 1.9 mgal and the mean became -0.03 mgal (see figure 9 histogram).
A comparison has been performed, showing the danger of adjusting solely the leg biases. As an example, figure 10 shows the gravity anomalies of cruise number 4 before and after correction using the full validation method as described here, whereas figure 11 shows the results one would get by adjusting only legs, without considering the drifts and biases of each cruise. In the last case, relatively high gradients between legs can be observed.
As a consequence, it appears that a satisfactory validation can only be attained if some good quality cruises (with good tie-ins at departure from and/or return to harbours) are available in the data set, which can be used as reference cruises, otherwise one will get "floating" solutions.

The map derived from the test case data (in the central part) is given on fig. 12.

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Table 1: Results of the prevalidation procedure

collocation method
rms=5 mgal
threshold to flag point is 15 mgal
maximum distance for regional smoothing is 30 km
correlation length is 15 km

cruise number	number of point	doubtful points	lapsed points
60000001	1156	0	0
60000002	1943	0	0
60000003	12142	0	0
60000004	3621	0	0
60000005	350	0	0
60000006	355	0	0
60000007	348	0	0
60000008	1007	4	2
60000009	907	0	0
60000010	1177	0	0
60000011	46539	2	0
60000012	20199	0	0
60000013	22372	0	0
60000014	58	0	0
60000015	519	0	0

Table 2 : DRIFT FOR EACH CRUISE

cruise number	drift mgal/day	number of crossovers	max t in day	min t in day
60000011	0.7988	73	9.841	1.018
60000012	-0.7917	445	3.021	1.002
60000013	0.2531	172	5.690	1.000

Table 3: BIAS FOR EACH CRUISE

cruise number	bias in mgl	number of crossovers
60000001	4.08	52
60000002	-84.04	10
60000003	-81.67	116
60000004	-73.62	116
60000005	15.53	31
60000006	-15.10	47
60000007	5.16	24
60000008	7.94	42
60000009	106.12	14
60000010	39.88	31
60000011	25.08	119
60000012	7.52	268
60000013	38.98	256
60000014	6.76	1
60000015	-2.62	9

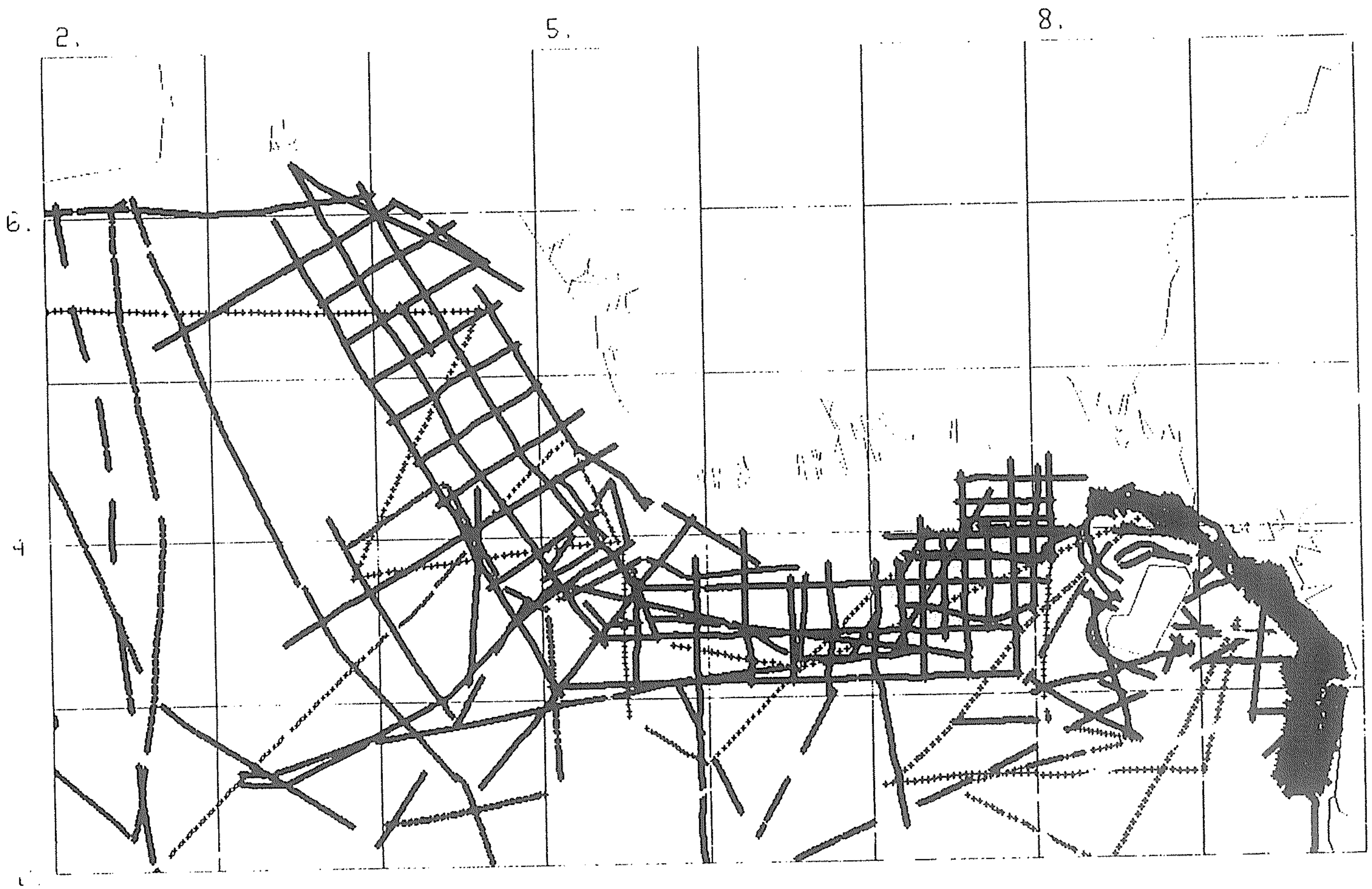


Figure 6: Distribution of sea gravity in data set

Figure 7: DRIFT RATE OF CRUISE 60000011

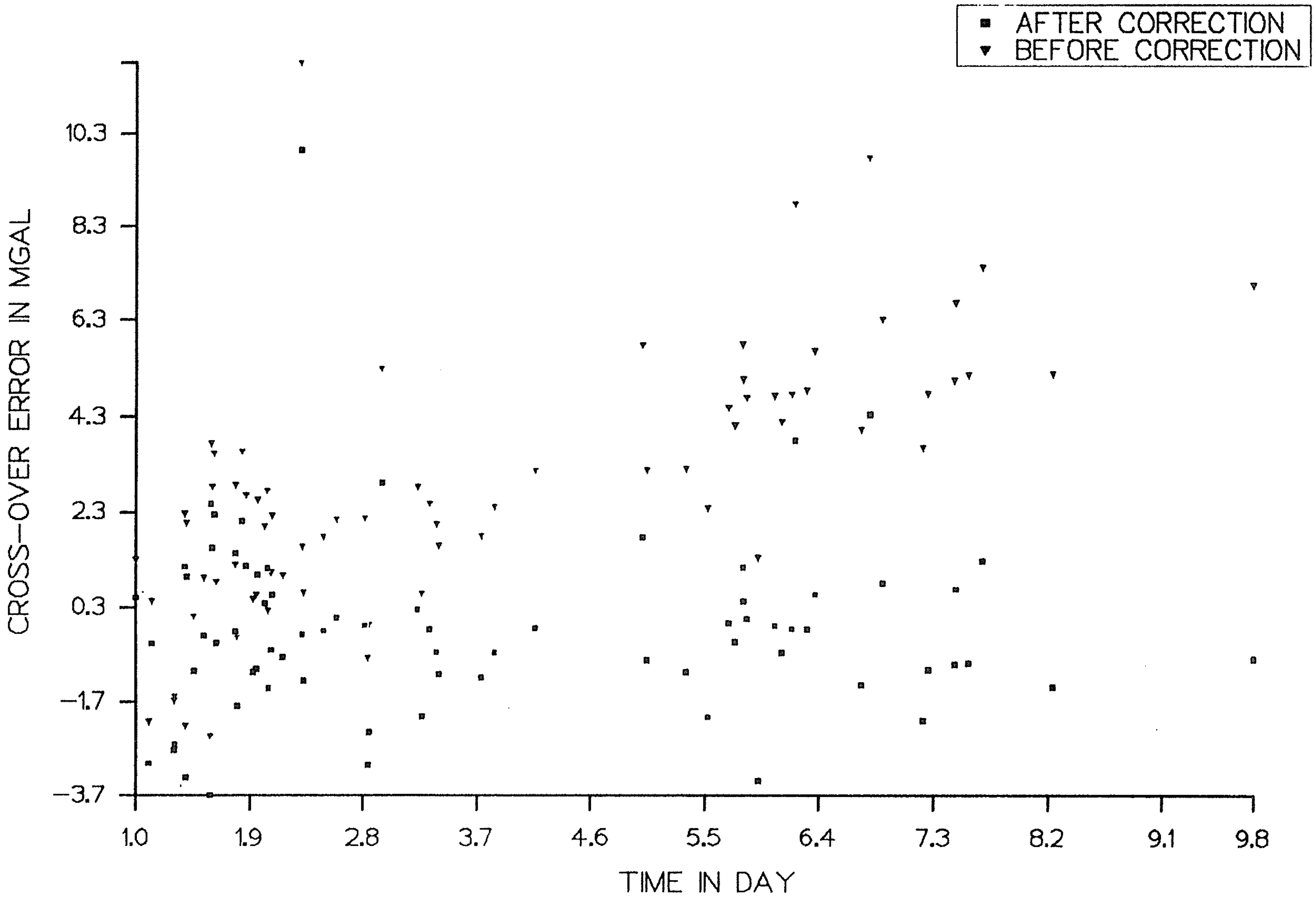
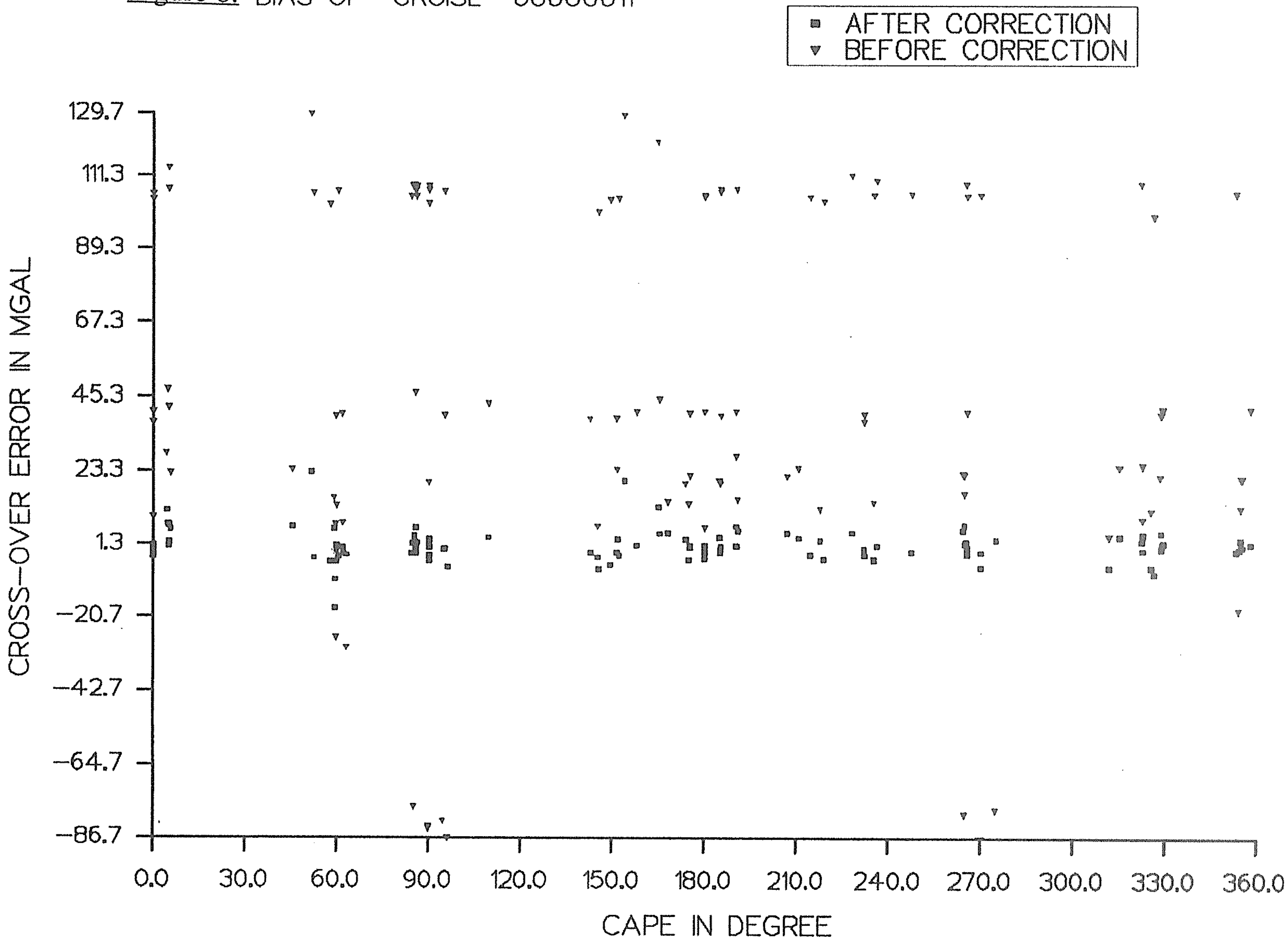


Figure 8: BIAS OF CRUISE 60000011



```
       HISTOGRAM BEFORE CORRECTION  RMS=         32.46131       MEAN= 12.61767

MIDPOINTS:  -105.38   -70.63   -35.88    -1.13    33.63    68.38   103.13   137.88   172.63   207.38
 COUNTS:         0.      17.      12.   1859.     227.      87.    141.      13.       3.       0.
                                                                  HISTOGRAM
Class ----------------------------------------------------------------------------------------------------------------------
  10   *                                                                                                                    *
       *                                                                                                                    *
   9   *                                                                                                                    *
       *                                                                                                                    *
   8   *                                                                                                                    *
       *                                                                                                                    *
   7   *IIIIIIII                                                                                                            *
       *                                                                                                                    *
   6   *IIIII                                                                                                               *
       *                                                                                                                    *
   5   *IIIIIIIIIIIIII                                                                                                      *
       *                                                                                                                    *
   4   *IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII *
       *                                                                                                                    *
   3   *                                                                                                                    *
       *                                                                                                                    *
   2   *I                                                                                                                   *
       *                                                                                                                    *
   1   *                                                                                                                    *
----------------------------------------------------------------------------------------------------------------------------
Frequency  5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85   90   95  100  105  110
           One frequency unit is equal to 16 count unit(s).

       HISTOGRAM AFTER CORRECTION  RMS=          1.92856       MEAN= -.03154

MIDPOINTS:  -105.38   -70.63   -35.88    -1.13    33.63    68.38   103.13   137.88   172.63   207.38
 COUNTS:         0.       0.       2.   2357.       0.       0.      0.       0.       0.       0.
                                                                  HISTOGRAM
Class ------------------------------------------------------------------------------------------------------------------------
  10   *                                                                                                                      *
       *                                                                                                                      *
   9   *                                                                                                                      *
       *                                                                                                                      *
   8   *                                                                                                                      *
       *                                                                                                                      *
   7   *                                                                                                                      *
       *                                                                                                                      *
   6   *                                                                                                                      *
       *                                                                                                                      *
   5   *                                                                                                                      *
       *                                                                                                                      *
   4   *IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII *
       *                                                                                                                      *
   3   *                                                                                                                      *
       *                                                                                                                      *
   2   *                                                                                                                      *
       *                                                                                                                      *
   1   *                                                                                                                      *
------------------------------------------------------------------------------------------------------------------------------
Frequency  5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85   90   95  100  105  110  115
           One frequency unit is equal to 20 count unit(s).
```

Figure 9: Histogram of crossover discrepancies

Figure 10: CRUISE 60000004

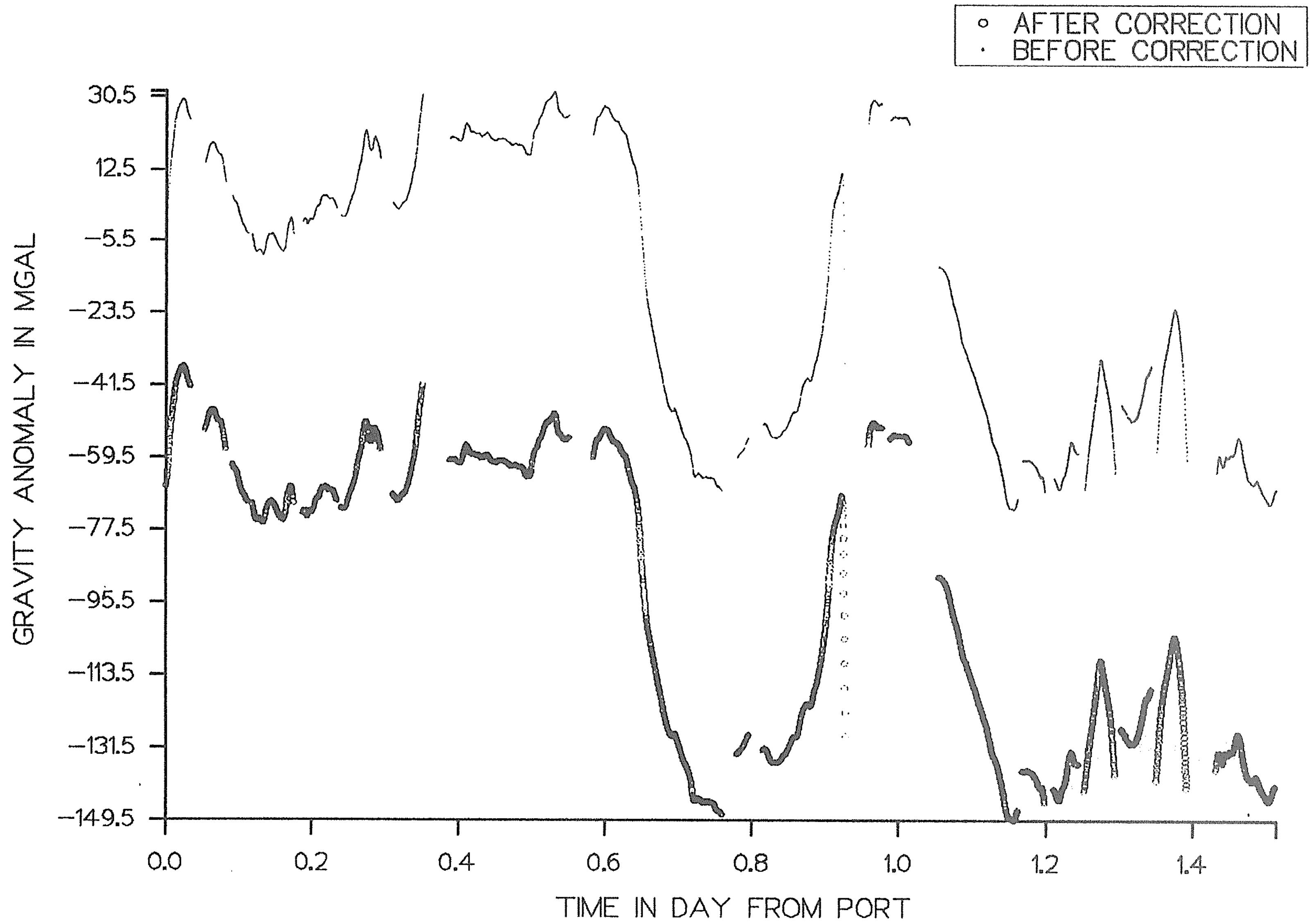


Figure 11: CRUISE 60000004

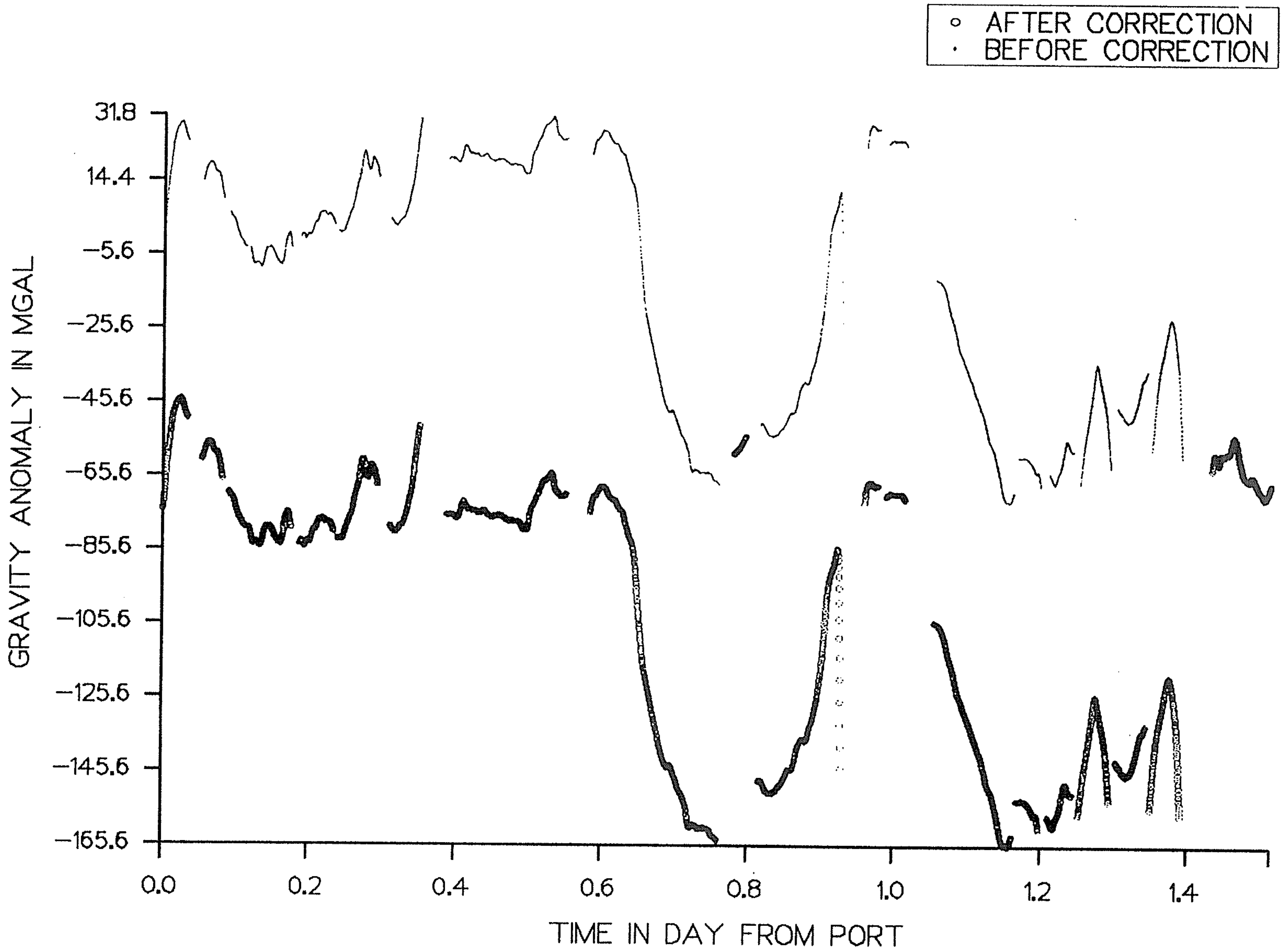
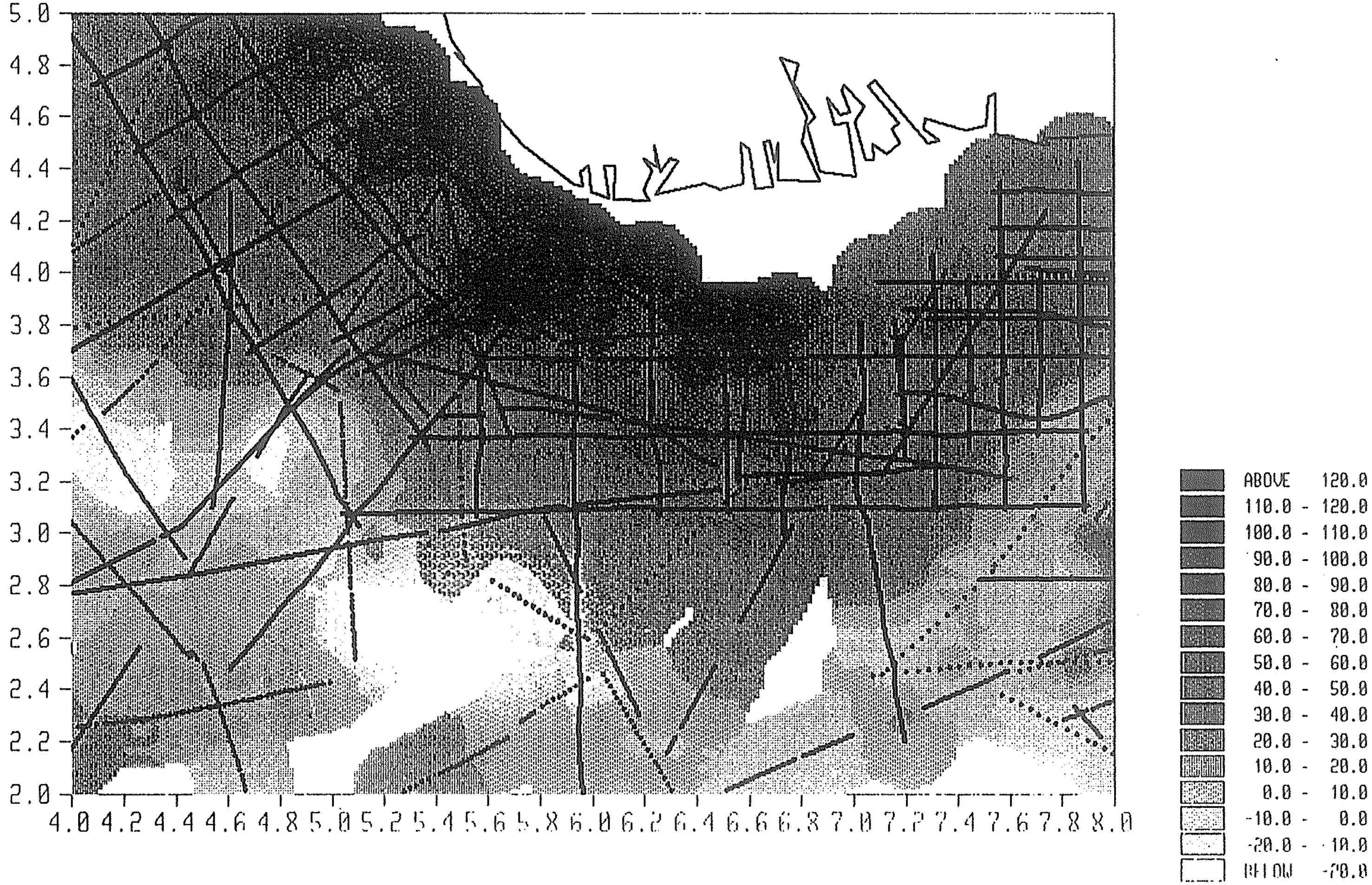


Figure 12 : Free-air gravity anomaly map derived from the test case data



WORKSHOP DISCUSSION

PROPOSED TOPICS :

1. Validation by cruise :
   - Filtering
   - Correlation with bathymetry
   etc...

2. Bias and tilt adjustment :
   - Separately vs. together

3. Definition of, and search for legs :
   - algorithms

4. Cross-overs : determination and management :
   - Basic searching techniques
   - Criteria for selection
   - Data base archival - updates (if any)

5. Utilisation of satellite derived data

6. Miscellaneous

...

MINUTES OF THE WORKSHOP DISCUSSION
Main remarks and Recommendations

1. VALIDATION BY CRUISE

- decimate the data : minimum distance ≈ 1 km.

- make use of : . Eötvös effect (a)
  . bathymetry (b)
  . signal gradient (c)

- experiment with MARVALID (GETECH) and SEAVALID (BGI) : may take too much time for the whole world ! Think of possibility of modifying GEOGRID (or similar software) for automated validation, in cases of discontinuities (to be detected and corrected for ?) ; this would require entering realistic auto- and crosscorrelation functions (with respect to (a), (b), (c)...).

2. BIAS AND TILT ADJUSTMENT

- Tilts should be determined only when time is known.
- Time interval should be long enough to solve for a drift parameter.
- Be careful with error estimates whjich are often irrealistic
- Be careful with constraints such as $\sum$ (bias) = o ; look at the age of the surveys, at the grouping of the cross-over biases before adjustment.
- Introduce harbour value when available.
- It is always better to have harbour ties at the beginning and end of a cruise : search for those.
- some reluctance to use satellite altimetry derived gravity information.

3. DEFINITION OF, AND SEARCH FOR LEGS

- is it (really/always) necessary to cut a cruise into legs ? this may be good only if connections between legs are realistic ; problem of weighting (to be tuned).
- criteria for leg definition : they seem all "equivalent" (good enough), as long as the number of obtained legs is not too much criteria dependent.

- use also information on Eötvös correction when available.

4. CROSS-OVERS : DETERMINATION AND MANAGEMENT

- line editing must be done before
- a cross-over archived file is necessary if the algorithm can make efficient use of it when adding new cruises (is there time saving ?)
- the searching technique at BGI looks fine : cell decomposition of the area and determination by block, the area being enlarged by one block size to allow for cross-over determination along the edges.
- a hierarchival system, with reference surveys, must be built to make sure the worldwide adjustment is manageable ; try to build up a system, "like IGSN", in which some good (harbour tied) cruises are kept fixed, then some "good" cruises are adjusted and kept fixed also, etc...
- it is noted that GETECH (Leeds) uses mostly Lhamont data in regional adjustments, and made use of well know, harbour tied-in cruises.

- 2 mgal is a dream ! with most (old) cruises, 5 to 10 mgal is more realistic ; this should be BGI's goal for a worldwide adjustment.

5. UTILISATION OF SATELLITE DERIVED DATA

- two basic methods : . inversion of derived geoid heights (by collocation, by FFT)
  . inversion of derived deviations of the vertical (same mathematical tools).
- examples : Haxby 5' x 5', Rapp 0.125° x 0.125°
- they are both good if correctly applied.
- they both need filtering of the basic quantity before inverting it.
- do not mix satellite data with ocean gravity data : satellite derived gravity should only be used for assessing that surveys are not connected to everything but not used for correction.

6. MISCELLANEOUS

- Bathymetry : . map also the cross-over differences, may be instructive
  . map the depths ; compare with ETOPO5, GEBCO...

- BGI should make software to map the location/magnitude of cross-overs.

- Air borne gravity data :
  . very similar to marine data
  . archival must be prepared by BGI (cf. Greenland data to be made available by Denmark in 1993) ; EOS format needs minor modifications : review the codes for data type (airplane, helicopter...), for elevation (with respect to the ice, a lake, ...) and the codes for positioning (GPS, GLONAS,...).

PART IV

MISCELLANEOUS

ABOUT THE COLUMBUS EGG...

Year 1992 has certainly excited the imagination of everyone, even our scientific colleagues !

Although some gloomy persons might look at the following pamphlet in a derogatory way (no one in our community, of course !), I felt it was worth publishing it here as a sign of enthusiam and good health of Science and its actors on the world scene... even if, as quoted by a famous journal managing editor "it is not of specific relevance to geophysics".

Have fun in reading it !

G. BALMINO

FOR INFORMATION

From: Naoshi FUKUSHIMA
Chofu-shi, Wakabacho 1-1-94
Tokyo 182, Japan

Dear Colleague,

Re: "Columbus' Egg" Idiom

Attached is the latest version of my article entitled "Columbus' egg", listing more than thirty versions of this popular idiom (which is unkown to English-speaking people) in various languages over the world. I am very grateful to those who kindly helped me in collecting these versions.

My interest in this linguistic subject was triggered about ten years ago, when I was the Secretary General of the International Association of Geomagnetism and Aeronomy (IAGA), with the help of an Australian secretary. One day I happened to learn that she did not understand the idiom of "Columbus' egg", although she had known of the famous fictitious episode of Columbus at the banquet to celebrate his successful trans-Atlantic voyage.

After the IUGG/IAGA General Assembly in Vienna in August 1991, I tried to finish my tracking of the "Columbus' egg" idiom in all European countries. As you will see in Table I of the attached paper, this idiom is understood almost everywhere in Europe except the United Kingdom, Poland, the Baltic countries, and Turkey. Inquiries into the versions in the languages of the new independent republics in East Europe remains as a future task.

In March this year I submitted this article to the English journal "Nature", and I received the following comment from the editor: "Although we read your manuscript with interest, I am afraid that it is rather far from our readers' interests for us to offer to publish it. Naturally, I regret our decision but wish you success in publishing your article elsewhere."

Then I submitted the same article in June to "Science" in the U.S.A., with the expectation that "Science" would be broad-minded enough to accept my essay as being of linguistic interest for all scientists over the world. However, it was again rejected because "it is not the sort of work they publish."

In July-August this year, the American Geophysical Union considered the publication of my article in EOS. I received the following statement dated August 12, 1992 from the EOS Managing Editor: "Our editors have decided not to accept it for publication, primarily because the topic, though interesting, is not of specific relevance to geophysics."

(p.t.o.)

These negative responses were not at all surprising for me, because the publishers in English-speaking countries might be reluctant to accept such an article that points out a specific peculiarity in their own language. Under these circumstances, I have given up my wish to publish the "Columbus' egg" essay in English-speaking countries. If you would like to publicize it (or Table I, with your own comments or remarks on "Columbus' egg") in your country, please feel free to do so. I would be of course very pleased if you introduce this interesting linguistic problem to your colleagues.

Prof. Robert Geller of the Department of Earth and Planetary Physics, University of Tokyo, who kindly checked through the manuscript of my essay, told me that English-speaking people often used the idiom "cutting the Gordian knot", instead of "Columbus' egg". Both of these idioms have a common meaning of "solving a very difficult problem through an unexpected, simple way", but the action for solving the problem is entirely different, namely, "with blade or brain." The former idiom of Greek origin must be popular in all European languages; in German it is "den gordischen Knoten durchhauen (zerhauen)", in French "trancher le noeud gordien", and so forth.

I would like to emphasize here again that it would have been impossible for me to write the attached report on "Columbus'egg" without your kind encouragement and collaboration; I am very grateful to you for notifying me of the version in your native language. It is really a great pleasure for me to send you here an up-to-date version of my report on "Columbus' egg" with many thanks to you.

12 September 1992

Yours sincerely,

Naoshi Fukushima

Naoshi FUKUSHIMA
(Professor Emeritus,
University of Tokyo)

Attach:

COLUMBUS' EGG

- A CONVENIENT IDIOM FOR SCIENTISTS ALL OVER THE WORLD, BUT ONE UNKNOWN TO ENGLISH-SPEAKING PEOPLE -

Some years ago I discovered that English-speaking people usually do not understand the phrase "Columbus' egg", though it is used in many other languages, including Japanese, as an idiom meaning "(to find) an unexpected, simple and clever idea for solving a seemingly impossible problem". A Japanese-English colloquial dictionary states that "deceptively easy" would be an adequate English-translation of what is meant by "Columbus' egg".

The origin of this idiom is a fictitious story about Christopher Columbus, in Girolamo Benzoni's book "Historia del mondo nuovo" (Venice, 1565), based on an episode involving the Italian architect Filippo Brunelleschi in connection with the construction of the dome of Santa Maria del Fiore in Florence. The story describes the following action of Columbus at a banquet hosted by Cardinal Mendoza in Barcelona in April 1493. After various speeches of congratulations for his first trans-Atlantic voyage, a man sneered at Columbus' success by saying, "Is it really worth admiring him for having succeeded in reaching America after sailing westward and westward ?" Columbus stood up immediately, taking up an egg from the table, and said: "Ladies and gentlemen! Would someone please try to make this egg stand up on its end on the table?" Those in attendance wondered why he made such a request of them; of course, nobody was successful in the effort. Then Columbus broke a very small portion of the egg shell by striking its end on the table carefully, and said, after showing the standing egg, "You will have no difficulty at all after someone has shown you the way."

In the history of science, occasional stepwise advances in our knowledge are due to "Columbus' egg" ideas. Hence, progress in science is often a compilation of a series of "Columbus' eggs". In these days English (or broken English) is generally used among scientists for international communication of their opinions and of new findings. We sometimes want to use "Columbus' egg" as an idiom for modestly introducing our own new ideas, but, unfortunately, this idiom is unknown in English.

We must be careful, however, because "Columbus'egg" sometimes has other meanings in some languages. I myself had the following interesting experience in Peru in November 1987. There I had the honour of giving a public talk in the municipal hall of Huancayo in commemoration of the 65th anniversary of the famous Huancayo Magnetic Observatory (established in 1922 by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, and later transferred to Peru in 1947). My speech in English was translated into Spanish sentence by sentence. I used some OHP viewgraphs, all of which were written in English except for one phrase, "Columbus' egg", shown in Spanish. I wanted to emphasize in my talk the importance of "Columbus' egg" ideas in the progress of the sciences, including geomagnetism.

As soon as I showed the phrase "Columbus' egg" in Spanish, the audience burst into laughter and I was embarrassed. I was told later that "Columbus' egg" in Spanish has a second meaning, which indicates a male organ. I insisted that the second meaning should not have come to mind because I showed the word in its singular form and not in the plural. However, the reply was: "It doesn't matter whether the word is in its singular or plural form".

I used the same OHP in my talks in Argentina and Brazil (in Brazil "Columbus' egg" was shown in Portuguese), with a special remark that this idiom is unknown to English-speaking people. The audience smiled after looking at this phrase, but they did not laugh out loud. Space scientists in Argentina and Brazil were more indulgent of my ignorance of their mother tongues.

In recent years I have tried to track the "Columbus' egg" idiom in various languages all over the world. Table I on page 4 shows my collection as of May 1992. You will see that the idiom is used in most of the European languages, and also in some other languages outside of Europe, e.g., Afrikaans, Wolof, Quechua, Indonesian, and even in Korean and Japanese.

The understandability of "Columbus' egg" in Japan seems to have originated from the fact that the so-called "Columbus' egg" story was explained in the national textbook for elementary schools starting in 1921. However, the story was deleted (to eliminate teaching materials of foreign origin), when the textbook was revised in 1942 during World War II, and unfortunately was not included in postwar textbooks. The wartime revision of textbooks has caused a gradual decrease in the popularity of the "Columbus' egg" idiom in Japan. In recent years, even some university students say they have never heard of the "Columbus' egg" idiom from either their parents or teachers. It is quite possible that future historians might point out that "Columbus was unable to reach ZIPANGU against his original expectation, but Columbus' egg came to Japan about 400 years later and it stayed there only during the 20th century."

The 500th anniversary of "Columbus' discovery of America" will be commemorated in 1992 with various ceremonial events. If English-speaking nations still call for some ideas to commemorate this anniversary, I would like to propose that they adopt "Columbus' egg" as a colloquial English idiom meaning "(to find) an unexpectedly simple and clever way of solving a seemingly difficult problem", or "deceptively easy." This could be a small token of thanks from English-speaking nations in return for their excessive advantage in international communication.

The author wishes of course to know if there are any languages other than those shown in Table I on page 4, in which "Columbus' egg" is used as a colloquial idiom; he thanks readers in advance for providing specific information on how this idiom is written in each language and what, if any, additional meanings it has.

Acknowledgments: I would like to express my thanks to the following persons who kindly helped me collect "Columbus' egg" "samples" in various languages: C.A. Van der Westhuysen and J.F. Herbst (for Africaans), B. Duka (Albanian), A.A. Ashour (Arabic), M. Kovacheva and S. Popova (Bulgarian), J.J. Curto (Catalan), Liu Q.-L. (Chinese), V. Hejduk (Czech), E. Friis-Christensen (Danish), M. Scherer (Dutch, Flemish and Polish), P. Tanskanen (Finnish), M. Teboul (French), J. McElwain (Gaelic), J. Untiedt and his students (German and Spanish), C. Giovas (Greek), P. Márton (Hungarian), T. Saemundsson (Icelandic), S. Saroso (Indonesian), G.P. Gregori (Italian), Pak B.S. (Korean), A. Date (Norwegian), Iranian Embassy in Tokyo (Persian), A.M. da Costa (Portuguese), M. Ishitsuka (Quechua), S.C. Rădan, A. Soare and R. Plaviţă (Romanian), G. Fischer and his friends (Romanch, Wolof and Yugoslav languages), V.G. Mikhalkovsky (Russian), M. Boda (Serbian), J. Podsklan and M. Hvozdara (Slovak), Swedish Embassy in Tokyo, M. Ebalo (Tagalog), and A.M. Işikara (Turkish). The author thanks also J. Wasilewski and R. Geller for their kindness in polishing this manuscript.

9 September 1992

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Table I. "COLUMBUS' EGG" idioms in various languages (as of May 1992)

コロンブスの卵 (*Japanese*)
코럼부스의달갈 (*Korean*)
Telur Colombus (*Indonesian*)
Nen ou Colomb (*Wolof in Senegal*)
Colonpa runtun (*Quechua in Peru*)
Die eier van Columbus, or Columbus se eier (*Africaans*)
Het ei van Colombus (*Dutch, Flemish*)
Das Ei des Kolumbus (*German*)
O ovo de Colombo (*Portuguese*)
El huevo de Colón (*Spanish*)
L'ou de Colom (*Catalan*)
L'uovo di Colombo (*Italian*)
L'oeuf de Christophe Colomb (*French*)
L'ov da Colŭmbus (*Romanch*)
Oul lui Columb (*Romanian*)
Kólumbusareggið (*Icelandic*)
Kolumbus æg (*Danish*)
Columbi egg (*Norwegian*)
Columbi ägg (*Swedish*)
Kolumbuksen muna (*Finnish*)
Kolumbusz tojása (*Hungarian*)
Veza e Kolombit (*Albanian*)
Kolumbovo vejce (*Czech*)
Kolumbovo vajce, or Kolumbusovo vajce (*Slovak*)
Colombovo jajce (*Slovenian*)
Colombovo jaje (*Croatian*)
Kolumbovo jaje, or Колумбово jaje (*Serbian*)
Колумбово jajце (*Macedonian*)
Колумбово яйцо (*Russian*)
Колумбово (or Колумбовото) яйце
or Яйцето на Колумб (*Bulgarian*)
Το αυγό του Κολόμβου (*Greek*)

[Note] In Japanese, the first five letters are phonetic ones (called katakana), and the next one is also a phonetic symbol (but hiragana) meaning "'s"; the last word meaning "egg" is rendered with a Chinese character (kanji). In Korean phonetic letters the first four are for "Co-lum-bu-s", the fifth is for "'s", and the last two are for "egg".

A direct translation of "Columbus' egg" is not used as a colloquial idiom in *Gaelic*, *Polish*, *Turkish*, *Arabic*, *Persian*, *Tagalog* and *Chinese* (哥倫布的难蛋). It is interesting to note that another Hungarian word for "egg" is spelled "mony" (which shows some similarity to Finnish), and this word is used in Transylvania (northern part of Romania and Hungary) now to mean just a testicle. In Italian, "colombo" also means "pigeon", and in its plural form means "a pair of lovers".